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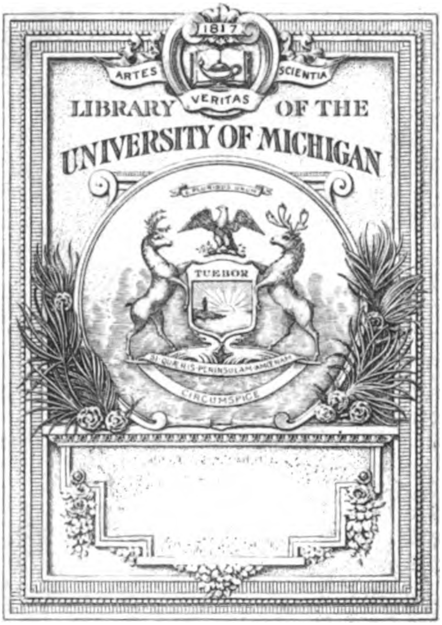

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QUARTERLY JOURNAL

OF THE

Royal Meteorological Society.

EDITED BY A
COMMITTEE OF THE COUNCIL

Vol. 49—1923.

LONDON:
EDWARD STANFORD, Ltd., 12, 13, & 14 LONG ACRE, W.C. 2.
1923.

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QUARTERLY JOURNAL

OF THE

ROYAL METEOROLOGICAL SOCIETY

VOL. XLIX.] JANUARY 1923 [No. 205

SOME NOTES ON ATMOSPHERIC TURBULENCE.

By A. E. M. GEDDES, O.B.E., D.Sc.

[Read at Edinburgh on July 24, 1922.]

WITHIN recent years Mr. G. I. Taylor has given a solution of the problem of the propagation of heat and momentum through the free air by means of eddy motion.[1] The methods of production of, and the effects produced by these eddies form an interesting study. In Figs. 1 and 2 are shown two examples of their effect on smoke leaving tall chimneys.

Both these examples refer to the same period of the year, viz. May-June. In the first the wind was ESE and about five miles an hour, with a high pressure centre in the neighbourhood of Iceland. The weather was fair, the sky being about one-third covered with cloud at a height of approximately 2000 feet. In the case of the other example the sky was entirely overcast with occasional mist but no rain. The wind was light as before, and from NNE. These conditions lasted for about three days.

In both these cases we see that low cloud was present, and that this cloud was of the stratus order. One might call it very low strato-cumulus or stratus-cumuliformis. Observation by aeroplane and kite-balloon has shown that very often an inversion of temperature is to be found above such clouds. On the other hand, above cumulus clouds inversions of temperature are never found, and therefore this stratus cloud is not formed by convection in the ordinary sense of the term.

As the upper layers must be getting cooled at the expense of the lower, a time must come when condensation takes place. Apparently that is what occurred in the examples now being considered. As the season of the year was May-June the land during the day was warmer than the adjoining sea. Also, considering the distribution of pressure, the air currents must have had their origin towards the north-east of the station at Aberdeen. The air therefore came off the sea and contained a fair quantity of water vapour. This air on passing to a surface which was warmer than the one it had left, *i.e.* a surface warmer than the lower layers of the air-current, was likely to have a fairly high eddy conductivity. This is shown by both the examples. Also as the ground was warmer than the air-current in contact with it, especially in the first case, the condensation did not take place right on the surface but at a level where the reduction of temperature by the eddy motion brought the temperature of the air below the dew point and so produced stratus clouds.

---

[1] "Eddy motion in the atmosphere," *Phil. Trans. R. Soc.*, **215** (ser. A), 1915, p. 1.

Turbulence at the base of a line-squall cloud is another phenomenon with which the meteorological observer is well acquainted. The eddies are perhaps not so well marked there as nearer the surface of the ground, but they are rendered quite visible by the formation of cloud patches. A line-squall which passed over Aberdeen on 7th April 1920 was accompanied by the cloud shown in Fig. 3. In the region where cloud forms in the line-squall front, there are two currents of different temperatures, and therefore of different densities. In the present instance the two temperatures were 42° F. and 36° F. approximately. The velocities of the two currents were also different and therefore eddy motion was produced at the boundary of the two masses. In the upward-moving current at least these eddies can be seen by the cloud fragments which have formed *below* the base of the main cloud, the presence of eddy motion being rendered visible by the slightly vortical appearance of the cloudlets.

Another effect of eddy motion is shown in Fig. 4. When a south-westerly to westerly type is prevailing, and the air comparatively dry, there are very often found in the neighbourhood of Aberdeen clouds which show a *quasi-lenticular* or roll formation. The example given in Fig. 4 will serve to show the type. When a cloud of this kind occurs there is always a marked difference of temperature between the west and east coasts, amounting on the average to 10° F. This difference in temperature is due, without doubt, to the föhn effect arising from the passage of the winds over the Grampians. Now Sir Napier Shaw has pointed out[1] that this heating effect arises from the air on the high ground with its large store of entropy being brought down to replace the colder air which has been scooped out apparently by eddy motion. The cloud formation appears to be in agreement with this theory. When the individual clouds are observed closely, it is found that they are not stationary as true lenticular clouds ought to be, but that they are moving forward bodily. Their velocity, however, is less than the velocity of the current in which they are found. Now the air is churned up by the eddy motion, becomes cooled down in the upper portions affected by the eddies, and condensation tends to take place. But in addition to its horizontal velocity the air has a wave motion arising partly from the nature of the surface it has passed over, and this wave motion is moving forward with a velocity different from that of the air itself. As already stated we are dealing with comparatively dry air, and therefore cloud formation is apparently found only when the eddy effect and the rarefaction produced by the wave motion are combined.

This would explain the strato-cumulus rolls shown in Fig. 4. This example was taken on the afternoon of 30th May 1922 during a westerly type. The actual difference of temperature between the west and east coasts was then 8° F., a difference which increased overnight to 13° F. The conditions demanded above are therefore fulfilled in this case with the result shown in the Plate.

To Mr. G. A. Clarke of the Aberdeen Observatory I am indebted for the photographs used in the illustration of these notes.

[The discussion on this paper was taken with that on the following paper, "Some examples of cirro-macula cloud."]

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[1] *Manual of Meteorology*, Pt. IV. (Cambridge Univ. Press), p. 51.

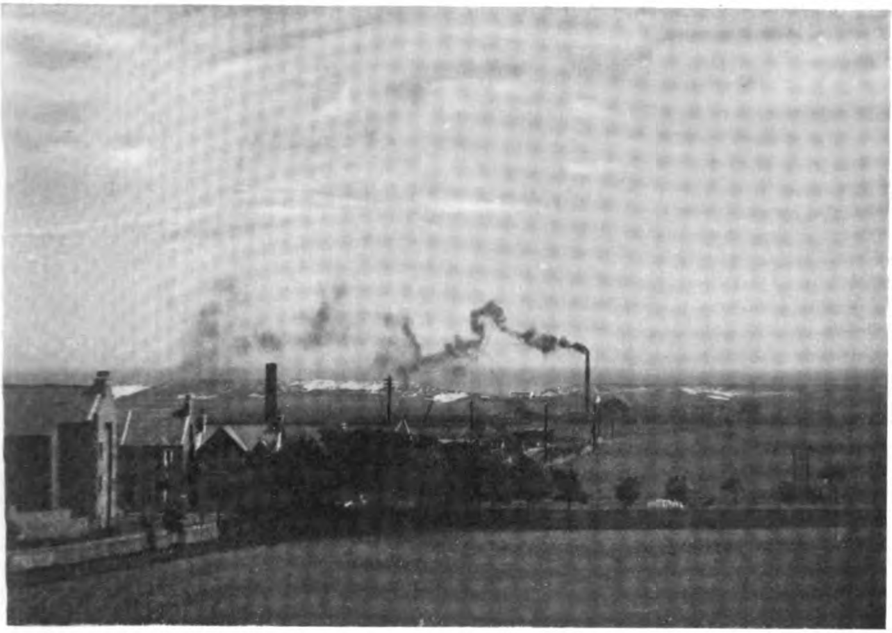

FIG. 1.—Example of eddy motion as shown by smoke leaving a tall chimney; wind ESE.

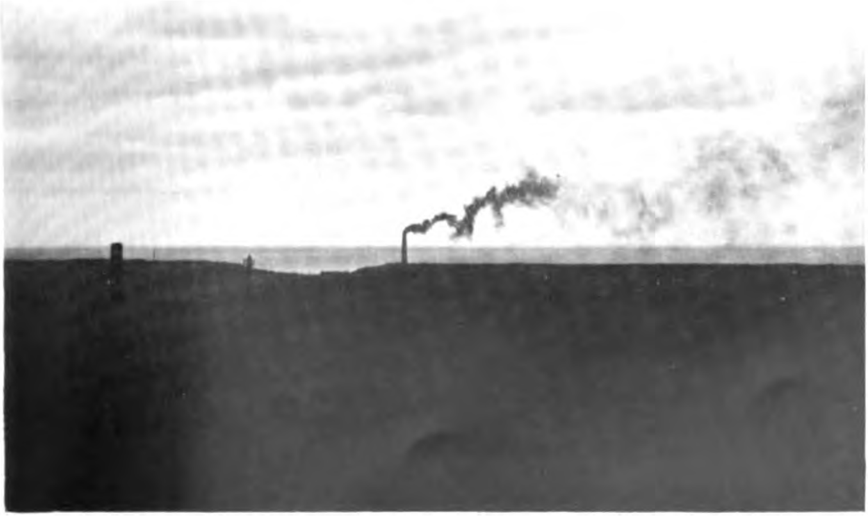

FIG. 2.—Further example of eddy motion; wind NNE.

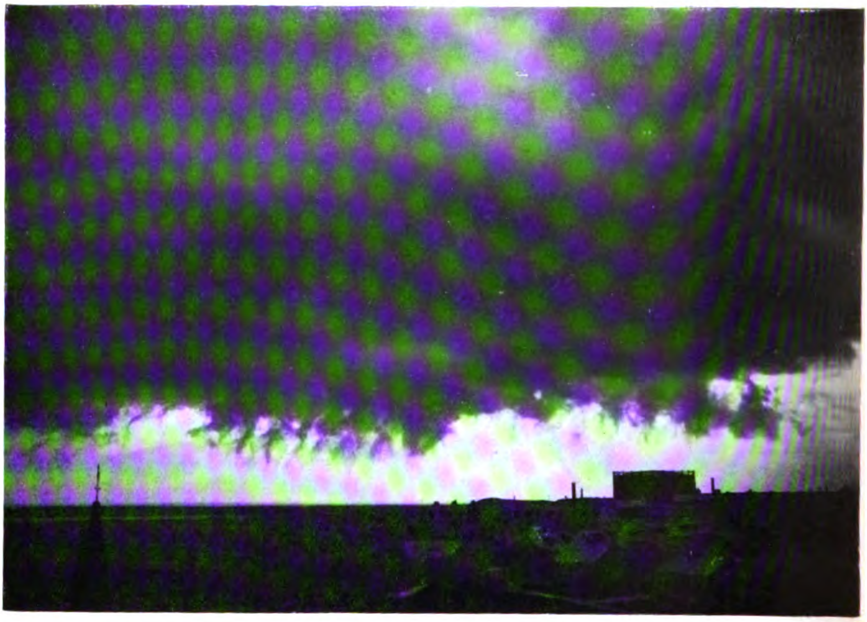

Fig. 3.—Cloud accompanying line-squall which passed over Aberdeen, 7th April 1920.

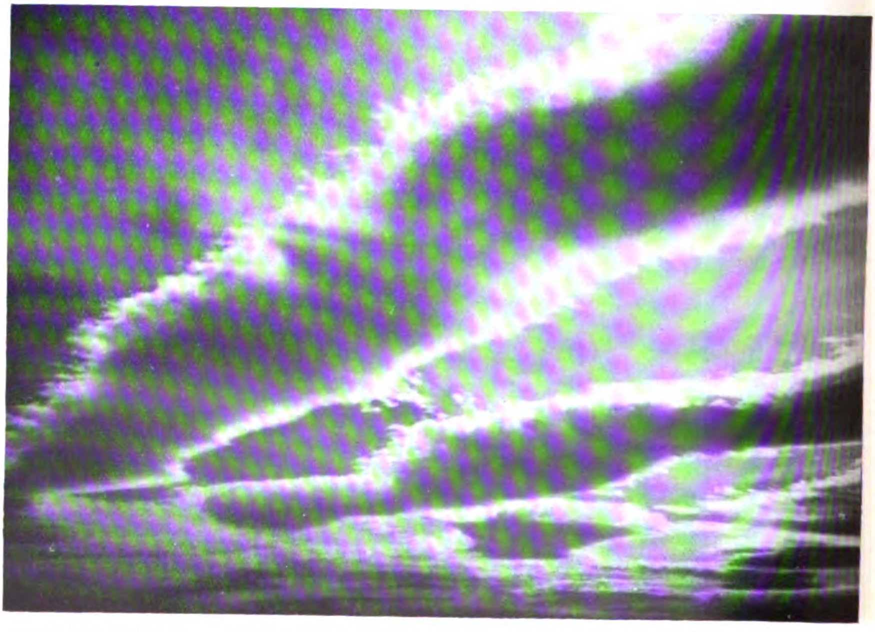

Fig. 4.—Long transverse waves of Alto-cumulus cloud changing to Strato-cumulus.

SOME EXAMPLES OF CIRRO-MACULA CLOUD.

BY G. A. CLARKE, F.R.P.S., The Observatory, Aberdeen.

[Read at Edinburgh on July 24, 1922.]

WRITING upon the "Forms of Cloud" [1] Captain C. J. P. Cave referred to the fact that it is not uncommon for ordinary cirrus cloud to change into cirro-cumulus, and drew attention to the need for future study to explain the phenomenon.

Cirrus, as Captain Cave remarked, is usually regarded as a cloud formed of ice-crystals, and the optical phenomena observed in this cloud are of the refraction type, haloes, parhelia, sun-pillars, and their concomitants. Cirro-cumulus, on the other hand, does not show refraction phenomena, but usually those of the diffraction type, such as coronæ and irisation. Therefore it is assumed that cirro-cumulus is a cloud of water-droplets.

There is, however, occasionally to be seen a type of cloud that is not definitely either cirrus or cirro-cumulus in its character, but somewhat of a compromise between these types. It is of extremely delicate structure, and of a very pure white colour; sometimes the cloud is very faintly visible, at other times its whiteness is intense,—this may probably depend upon the actual density of the cloud particles.

Speaking generally, the form of cloud is that of tiny globular or macular aggregations of condensation connected together by a network of threads. Sometimes the cumulus character is dominant, at other times the thread structure is the chief feature, while frequently both characteristics are co-existent. But in all cases the one outstanding attribute of the cloud is that of continual change from the one form to the other.

This change was remarked upon by Captain Cave, and, as I have already mentioned, he drew special attention to the very remarkable fact that cirrus often develops into cirro-cumulus. My own observations tend to show that this change occurs much more commonly than the reverse process, despite the fact that at the altitudes where these clouds are found, the temperatures must usually be well below the freezing point. Captain Cave remarks that it is quite easy to understand that cirro-cumulus composed of supercooled water-droplets might very readily become converted into the ice-crystal cirrus, but that it is very difficult to imagine the reverse process.

It has lately been suggested by the American meteorologist, Dr. C. F. Brooks, that the term cirro-cumulus should not be applied to any high cloud that shows diffraction phenomena, or which, in other words, is composed of water-droplets. It would therefore appear that the name "cirro-cumulus," which cloud, according to Dr. Brooks's definition, must be of ice-crystal structure, should be applied to this intermediate cloud I have just described. But actually, I have observed all gradations between this "cirro-macula," as it is termed by Clement Ley, and the normal cirro-cumulus of the International Classification.

The crucial test of whether the cloud gives *refraction* or *diffraction* phenomena is not easily applicable, because the cloud in question occurs in comparatively small isolated patches over the sky, and is not always sufficiently near the sun's disc for the test to be applied.

---

[1] *Q. J. R. Meteor. Soc.*, **43**, 1917, p. 61.

Since the appearance of Captain Cave's paper this cloud has been carefully watched at Aberdeen, and though coronæ have sometimes been seen in it, I cannot recall a single instance of halo-phenomena. The number of optical observations are, however, too few to warrant any definite statement upon the matter.

Observations and further investigations of this cloud type are still proceeding at Aberdeen, but accompanying this paper are a few photographs of this cloud-type, together with descriptions of their salient features. I should be very grateful if Fellows of the Society who have any opinions or explanations to offer upon the subject would kindly do so.

The question is this: "Is the cloud composed of ice-crystals, as is the case with the normal cirrus, or of minute water-droplets, or may there be some intermediate condition? And are we to continue to classify cirro-cumulus according to the International System, or to reserve that name for this cirro-macula form?"

The custom at Aberdeen is to record this latter type as "cirrus to cirro-cumulus," on account of its changing condition.

[Eighteen lantern slides of these clouds were shown at the meeting and described. Eight of these are here reproduced with descriptive text.—*Editing Committee.*]

DISCUSSION.

Mr. C. K. M. Douglas said, with regard to the formation of sheets of strato-cumulus over the sea, that if the addition of heat at the surface resulted in a fall of temperature at the height of a few thousand feet, it would be a remarkable paradox of which there is no observational evidence yet available. The low temperature at the cloud level could be explained by the source of the air and outward radiation from the damp layer, the turbulence which maintains the clouds being a consequence of the high lapse rate. A temperature inversion is by no means always present above horizontal sheets of cloud.

Turning to the question of cirro-cumulus clouds, Mr. Douglas agreed with the authors of the paper that the classification suggested by Dr. Brooks was not practicable, but he thought that a suggestion made by Dr. Brooks in an earlier paper[1] threw some light on the remarkable transformations illustrated by Mr. Clarke's photographs. It was suggested that the evaporation of ice-crystals or small snow-flakes reduces the temperature, and that the resulting high lapse rate produces turbulence and a thin sheet of cloud. The suggestion referred primarily to alto-cumulus forming below cirro-stratus, but it may readily be applied to cirro-cumulus forming at the same level as a gradually dissolving mass of cirro-stratus. He (Mr. Douglas) had often observed thin layers of super-cooled water-drop clouds in the middle of thinly scattered ice-crystals. These layers are usually slightly turbulent, and the particles are probably continually being evaporated and re-formed, which is perhaps favourable to water-drops rather than ice-crystals. The ice-crystal clouds are usually very diffuse, occupying a layer several hundreds or even a few thousands of feet thick.

Dr. Geddes, in his reply to Mr. Douglas, said that the type of cloud particularly referred to was stratus or stratus-cumuliformis. Observations by

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[1] Brooks, C. F, "A cloud cross-section of a winter cyclone," *Washington, D.C., U.S. Dept. Agric. Mon. Weath. Rev.*, **48**, 1920, pp. 26-28.

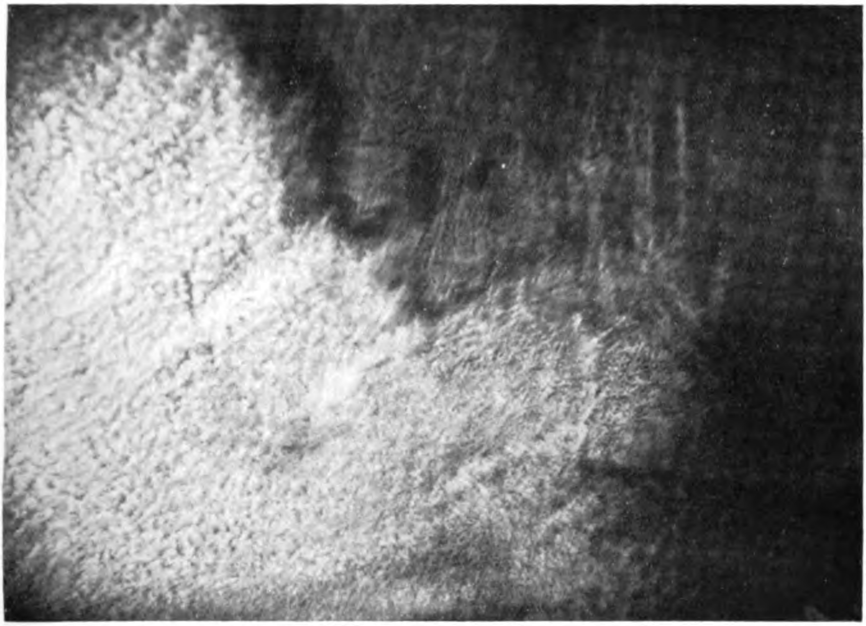

FIG. 1.—Cirro-macula cloud showing a progressive development from thread to globular form.

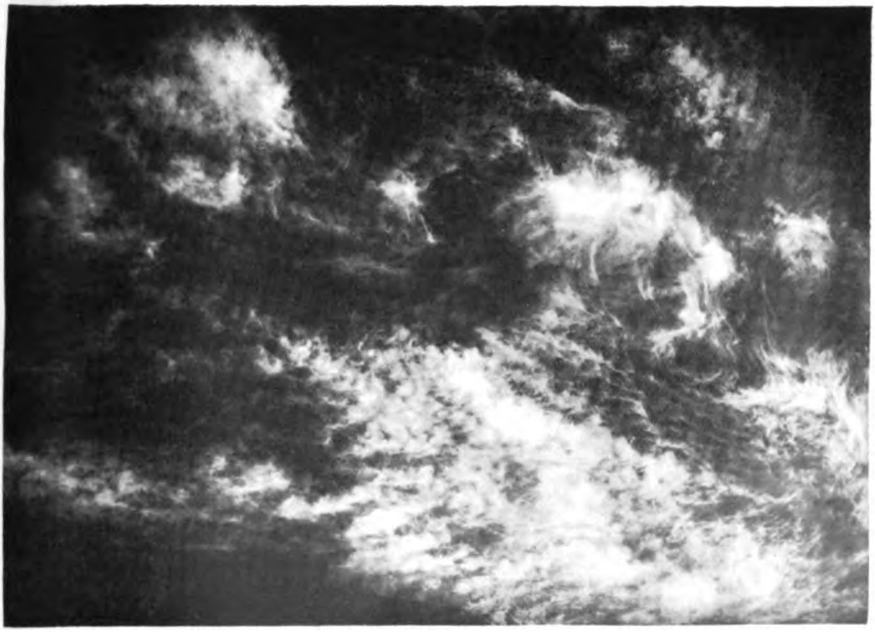

FIG. 2.—Attention is drawn to the very delicate thread-ripples near the lower right-hand corner. These were the first evidences of an undulatory influence that rapidly altered the appearance of the cloud-sheet into the form shown in Fig. 3.

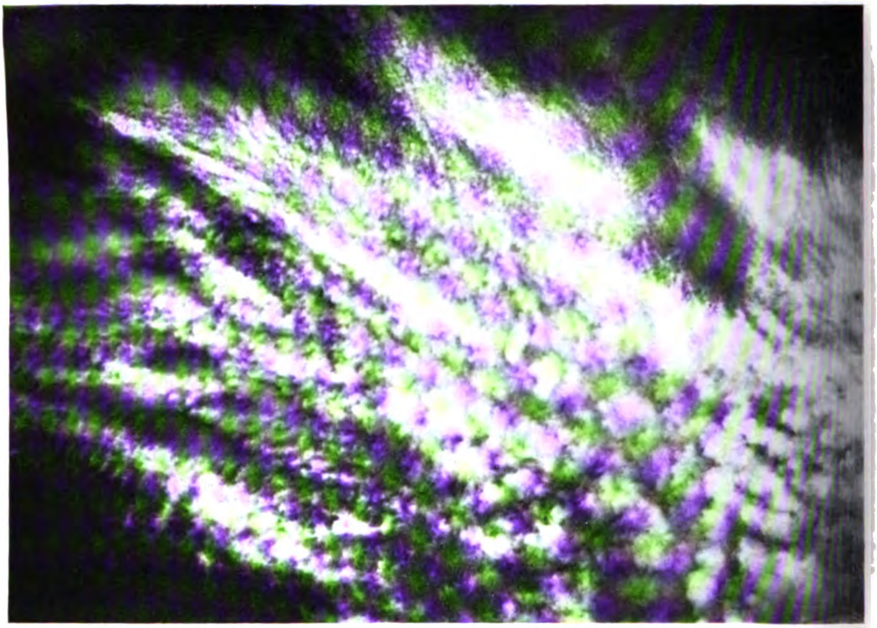

FIG. 3.—A dramatic change from Fig. 2 which took place in about ten minutes. The great variation in the sizes of the individual globular cloudlets is noteworthy, which in this instance were of normal Cirro-cumulus type.

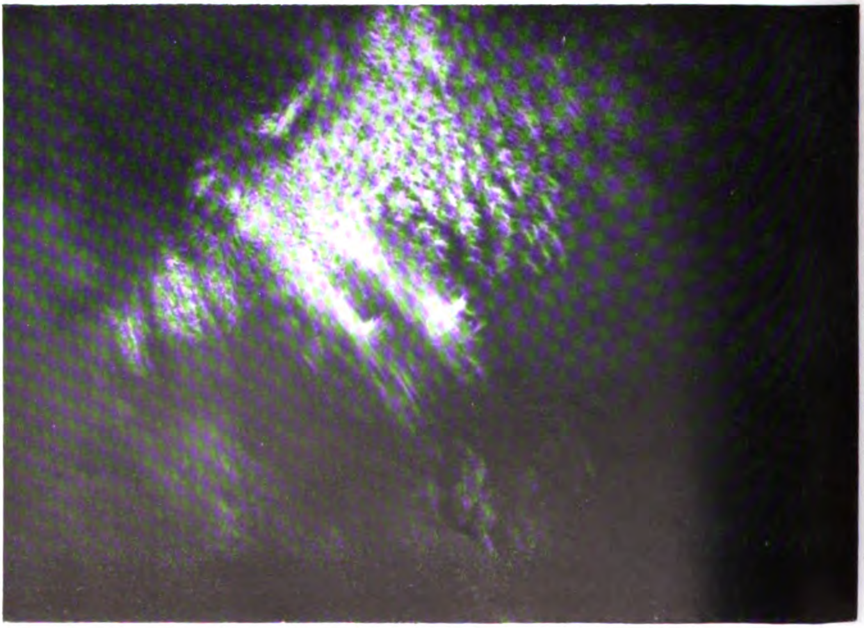

FIG. 4.—Figs. 4 to 6 illustrate an example where the thread type gave place to the "macula" form. In Fig. 4 the Cirro-macula is seen mixed with some definite threads of Cirrus.

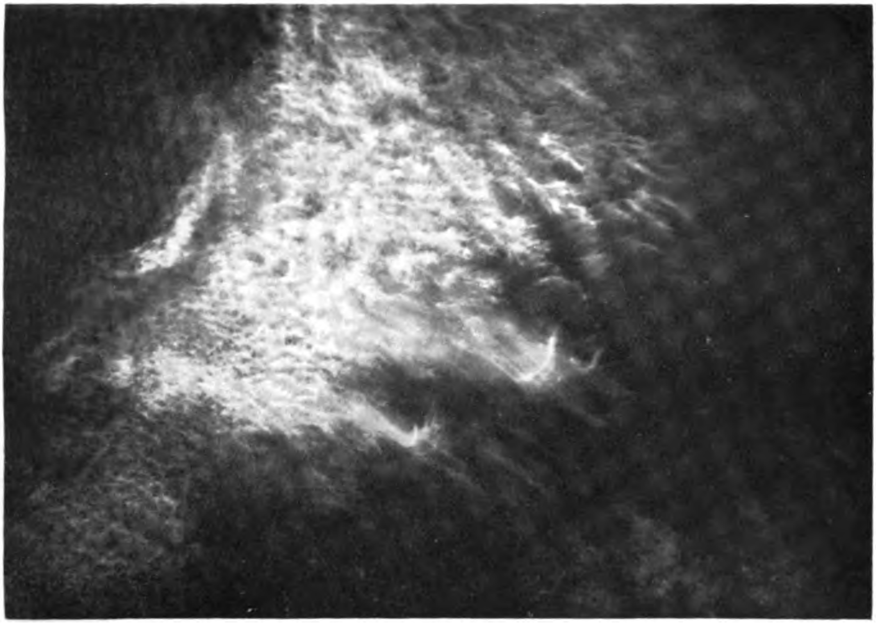

Fig. 5.—The threads of Cirrus are much less evident than in Fig. 4, taken a few minutes earlier.

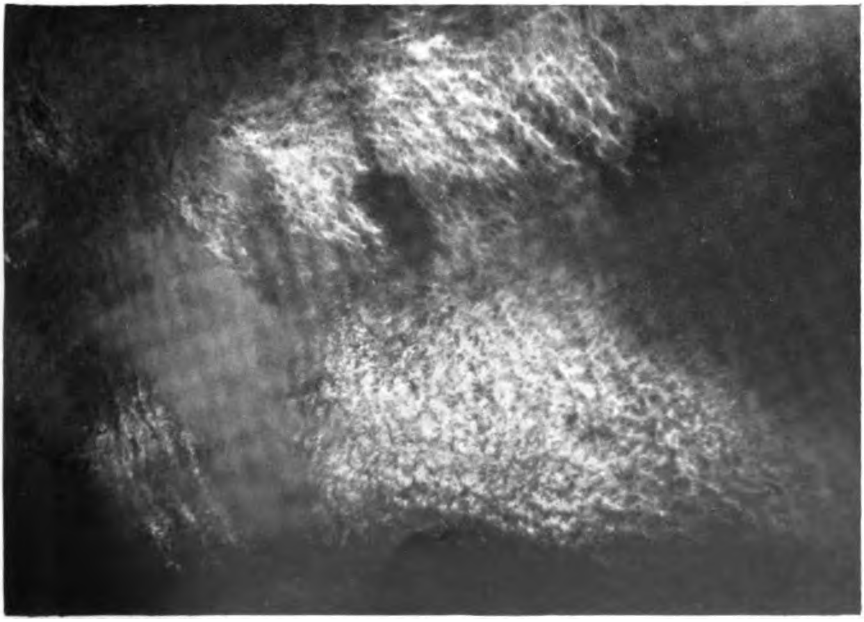

Fig. 6.—The threads of Cirrus have now disappeared entirely, and the form of the cloud itself has altered considerably.

Q. J. R. Meteor. Soc., Vol. **49**, 1923, Pl. V.

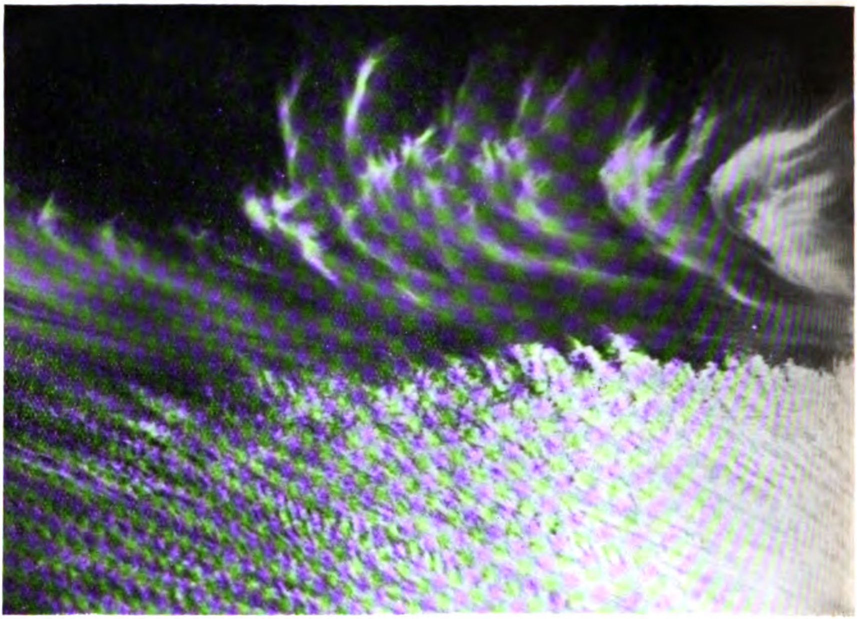

FIG. 7.—Sheet of small Cirro-cumulus, showing a very beautiful Cirrus edge.

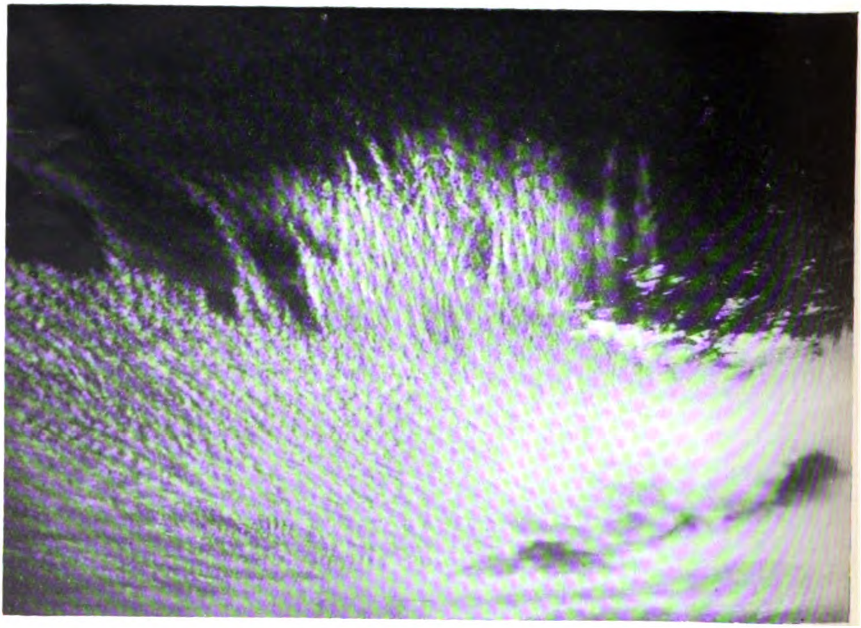

FIG. 8.—The same cloud as shown in Fig. 7 photographed shortly afterwards, with the Cirrus edging developed into very delicate Cirro-macula.

kites showed that an inversion of temperature above such clouds was the rule rather than the exception. The formation of cloud of this type with an inversion of temperature above it was dealt with by Sir Napier Shaw.[1] There he (Shaw) considered that the increase in turbulence caused by the addition of heat at the surface resulted in the eddy motion reaching to a greater height, and causing a more uniform distribution of potential temperature. Thus the upper layers affected by the turbulence became cooled and condensation took place. In the region above not affected by the turbulence there would be no reduction of temperature and therefore an inversion was to be expected. The explanation of this reduction of temperature and consequent cloud formation did seem possible therefore by the addition of heat at the surface, paradoxical though it appeared at first. Further investigation was required to decide, however, whether this explanation or that offered by Mr. Douglas was the more correct.

Mr. G. A. CLARKE in a written reply said that he was much interested in the statement made by Mr. Douglas regarding the frequent occurrence together of thin layers of supercooled water-drops and thinly scattered ice-crystals; and also in his suggestion as to the probable cause of the changes of the cloud.

In no case, however, among the examples shown, had the change occurred in gradually dissolving masses of cirro-stratus; but rather in cloud of a very transitory character, which had formed quite suddenly as a few threads of cirrus out of a clear blue sky, changed thereafter into the cirro-macula form, usually in a very few minutes, and then evaporated completely.

Such rapid changes would, as Mr. Douglas remarked, be more likely in clouds of a water-droplet constitution than in those of an ice-crystal one; it would be interesting to know whether the thread-like form may not be possible with water-drops as well as with ice-crystals.

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[1] *Loc. cit.* p. 48.

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In view of the infinite variety of cloud forms which occur, and the interest of cloud photographs to the meteorologist, it has been decided to keep a portfolio of cloud photographs at the Society's Rooms.

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Award of the Buys Ballot Medal, 1923, to Sir Napier Shaw, F.R.S.

The medal was founded in 1888 in commemoration of the work of C. H. D. Buys Ballot, the famous meteorologist of the Netherlands, to be awarded by the Royal Academy of Science at Amsterdam every tenth year to the person judged to have made the most valuable contributions to the science of meteorology. The medal is to be given this year to Sir Napier Shaw, F.R.S., Professor in the Royal College of Science, late Director of the Meteorological Office, for contributions to all branches of the science, and specially for his work as President of the International Meteorological Committee. The previous awards were: 1893, Dr. Julius Hann of Vienna; 1903, Dr. R. Assmann and Dr. A. Berson of Berlin, jointly; 1913, Dr. H. Hergesell of Strasbourg.

CIRCUMSTANCES DETERMINING THE DISTRIBUTION OF TEMPERATURE IN THE UPPER AIR UNDER CONDITIONS OF HIGH AND LOW BAROMETRIC PRESSURE.

By A. H. R. GOLDIE, M.A.

[Received October 14—Read November 22, 1922.]

THE present paper has a twofold object in view. It advances a possible explanation of the more important changes of atmospheric pressure in temperate latitudes; at the same time it shows that the statistical relations found to exist between temperature and pressure at various heights as well as other ascertained facts regarding the height of the stratosphere, etc., can be largely accounted for by consideration of horizontal movement of masses of air, and that vertical motion other than on a very gradual and quite local scale need not be brought in.

1. In July 1915 Hesselberg[1] gave an interesting mathematical discussion of certain aspects of the relation between temperature and pressure. Taking the statement that pressure changes at ground level are called forth by those at 9 kilometres, he examines the effect of the simple introduction of a mass of air above the 9-kilometre level, the same air as formerly remaining below that level. He deduces an expression connecting temperature-change with pressure-change for any point below the 9-kilometre level, and shows by numerical examples that the change of temperature produced by a given change of pressure is only about one-third of that required by the statistical relation.

Next he takes the simple introduction of a mass of air at the surface, the same air as formerly remaining above, and finds that this provides an even less adequate explanation. Therefore he says: "The air masses which are found in the column from 0 to 9 kilometres after the pressure-increase must have a higher mean temperature than those which were formerly there,—independently of where the masses producing the pressure increase are introduced, whether above or below the 9-kilometre level."

To discuss the question further he proceeds most logically to find the most general mathematical expression for temperature-increase per unit of time at a point in space. The co-ordinate axes are taken as follows: X—axis towards east, Y—axis towards north, Z—axis vertically upwards. Using the operator "d" to apply to changes undergone by a given particle of air and "∂" to apply to changes at a point in space, we have, for the changes produced by the communication of a small quantity of heat to a given mass of air—

$$dQ = c_p d\theta - A\alpha\, dp \quad . \quad . \quad . \quad . \quad (1)$$

whence

$$\begin{aligned}\frac{dQ}{dt} &= c_p\frac{d\theta}{dt} - A\alpha\frac{dp}{dt}\\ &= c_p\left\{\frac{\partial\theta}{\partial t} + v_x\frac{\partial\theta}{\partial x} + v_y\frac{\partial\theta}{\partial y} + v_z\frac{\partial\theta}{\partial z}\right\}\\ &\quad - A\alpha\left\{\frac{\partial p}{\partial t} + v_x\frac{\partial p}{\partial x} + v_y\frac{\partial p}{\partial y} + v_z\frac{\partial p}{\partial z}\right\} \quad . \quad . \quad . \quad (2)\end{aligned}$$

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[1] Hesselberg, Th., "Über den Zusammenhang zwischen Druck- und Temperaturschwankungen in der Atmosphäre," *Met. Zeit.*, **32**, 1915, pp. 311-318.

$$\therefore \frac{\partial\theta}{\partial t}=\frac{1}{c_p}\cdot\frac{dQ}{dt}-\left\{v_x\frac{\partial\theta}{\partial x}+v_y\frac{\partial\theta}{\partial y}+v_z\frac{\partial\theta}{\partial z}\right\}$$
$$+\frac{A\alpha}{c_p}\left\{\frac{\partial p}{\partial t}+v_x\frac{\partial p}{\partial x}+v_y\frac{\partial p}{\partial y}+v_z\frac{\partial p}{\partial z}\right\}\quad . \quad . \quad . \quad . \quad (3)$$

Now $v_x\frac{\partial p}{\partial x}+v_y\frac{\partial p}{\partial y}$ is actually zero if the motion is geostrophic; at all events it should be negligible.

$$\therefore \frac{\partial\theta}{\partial t}=\frac{A\alpha}{c_p}\left\{\frac{\partial p}{\partial t}+v_z\frac{\partial p}{\partial z}\right\}-\left\{v_x\frac{\partial\theta}{\partial x}+v_y\frac{\partial\theta}{\partial y}+v_z\frac{\partial\theta}{\partial z}\right\}$$
$$+\frac{1}{c_p}\cdot\frac{dQ}{dt}\quad . \quad . \quad . \quad . \quad . \quad (4)$$

This is simply the mathematical way of saying that if the temperature of the air at a given point in space changes, the change is the combined result of the following possible causes:—

(1) Adiabatic change due to change of pressure.
(2) Change due to introduction—horizontally or vertically—of air of a different temperature from neighbouring regions.
(3) Contribution of heat to or abstraction of heat from the air by radiation, convection, condensation, etc.

Hesselberg writes the above expression in another form and gives it as his opinion that the terms involving v_z, *i.e.* vertical motion, are the important ones from the point of view of an explanation of the statistical relations between temperature and pressure. I hope to show later the importance of the terms in v_x and v_y, and particularly of the latter, *i.e.* of the introduction, by ordinary horizontal motion, of air of a different temperature from more northerly or more southerly latitudes.

2. The appropriate course for an investigation on these lines appeared to be the examination in detail of a fairly complete series of daily upper air observations, combined with a study of the trajectories of individual specimens of air.

Observations of temperature made from aeroplanes in this country from October to December 1921 were chosen for examination. The readings were made first at the surface, then at 1000 feet, and thereafter at heights corresponding to pressures of 950, 900, 850, 800, 750, 700, 650, 600, 550 and 500 millibars, or to as great a height as weather and other conditions permitted. The data were taken from the *Daily Weather Reports* (British and International Sections and Upper Air Supplement) of the Meteorological Office. In all, 165 ascents were available. From a consideration of the synoptic charts and all upper wind information available, a decision was made in respect of each ascent as to whether it had taken place—

(*a*) entirely in equatorial air; or
(*b*) entirely in polar air; or
(*c*) partly in one, partly in the other.

A few cases of (*c*) were found and were set aside for special examination.

Dealing separately with (*a*) and (*b*), the correlations between temperature and pressure were calculated for each month, for the two regions 950-750 millibars and 700-500 millibars. It will be noted that these correspond roughly to the regions ½ to 2½ km. and 3 to 5 km.; but in working out the correlation coefficients consideration of height was left out and temperature was dealt with simply in relation to pressure.

[The coefficients do not therefore relate to pressure and temperature at the same level.]

The results were as follows:—

TABLE I.

Period.		Region 950-750 mb.	Region 700-500 mb.
September,	Equatorial	·797	·835
	Polar	·707	·678
October,	Equatorial	·653	·881
	Polar	·558	·748
November,	Equatorial	·734	·858
	Polar	·705	·525
December,	Equatorial	·680	·905
	Polar	·759	·725
Mean (all 4 months),	Equatorial . .	·72	·87
	Polar . . .	·68	·67

The following points emerge:—

(1) The coefficients are slightly higher than those of Dines for corresponding heights.

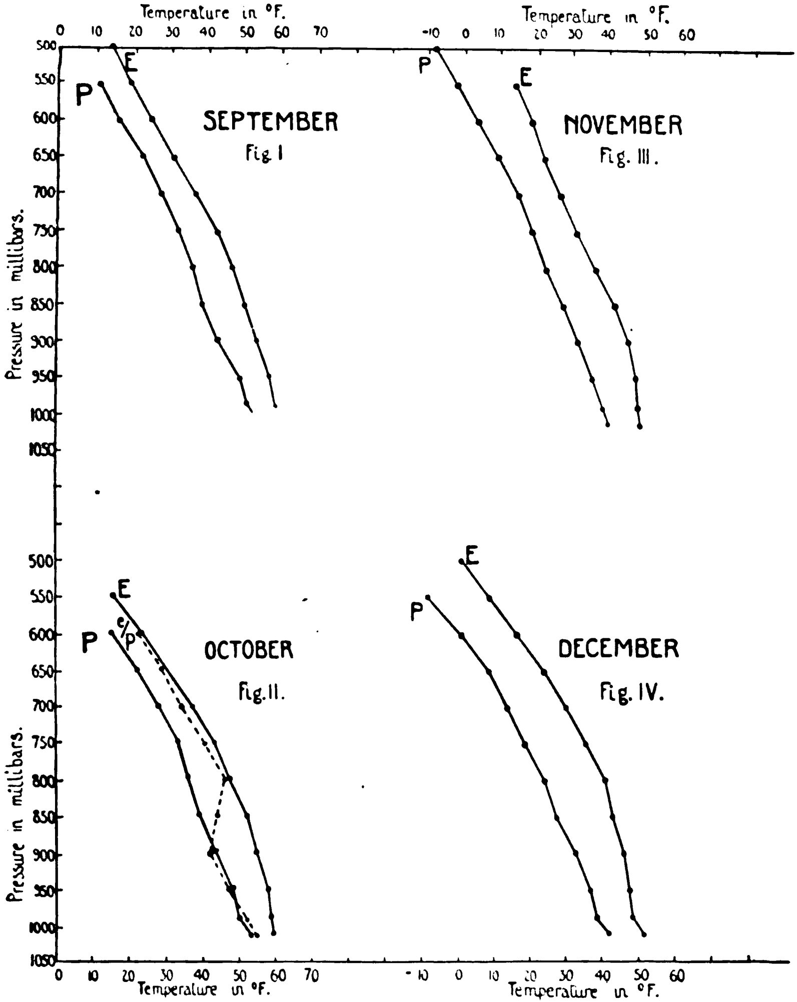
(2) In seven out of the eight individual cases the correlation in the case of equatorial air is higher than in the case of polar air.

(3) In equatorial air the correlation in the region 700-500 mb. is in every case decidedly higher than in the region 950-750 mb. In polar air there is little difference.

The reason for the second and third points is probably as follows.

Air which has spent a long time in polar regions will have reached something like a definite steady state in so far as temperature at a definite height or pressure is concerned; air which has spent a long time in equatorial regions will probably have reached a state in which a given temperature is even more definitely associated with a certain pressure. So that in each case, but more accurately in the latter, temperature might be written as a function of pressure. When the equatorial air moves towards temperate latitudes the cooling will be largely confined to a comparatively shallow surface layer; when, however, polar air moves southward, it will be warmed in the surface layers, and this effect will keep on being propagated upward. In the end, temperature at a given pressure in polar air found in our latitudes will be a function depending on its original state and on the time that has elapsed and on the course taken by it on its way from polar regions. But temperature in equatorial air will still, apart from a shallow surface layer, remain practically as definitely a function of pressure as it was when it left equatorial regions. Hence the higher correlation in the case of equatorial air.

3. The mean relations of temperature to pressure in the months under consideration are shown in Figs. 1 to 4. It will be noted that the curves for polar and equatorial air are of an appreciably different shape, resulting in a maximum difference of temperature at about 850 mb. It will also be noted that at all heights considered, *i.e.* up to about 5 km., there is a very definite difference of temperature between polar and equatorial air. This does not support the view that a cyclone is symmetrical above, and, whilst it might be legitimate to state that there is no definite relation between temperature and wind direction in the upper air levels,[1] it would not be correct to state that there is no



Curves showing the relationship between temperature and pressure in Equatorial (E) and Polar (P) Air respectively.

The dotted curve $^e/_p$ is the mean of six cases of Equatorial above Polar Air.

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[1] Dines, W. H., *Meteor. Off., Geophys. Mem.* No. 2, 1912.

relation between temperature and the source of the air in question. There may be symmetry close to the centre or at great heights, though I doubt the latter.

In October six cases of equatorial air above polar air were found among the ascents, five of them from about 850 mb. upward, the other from about 800 mb. upward. The mean curve from these six is shown as the dotted line *e/p* in Fig. 2, and is interesting in that it shifts from the average polar to the average equatorial curve in a noticeable way.

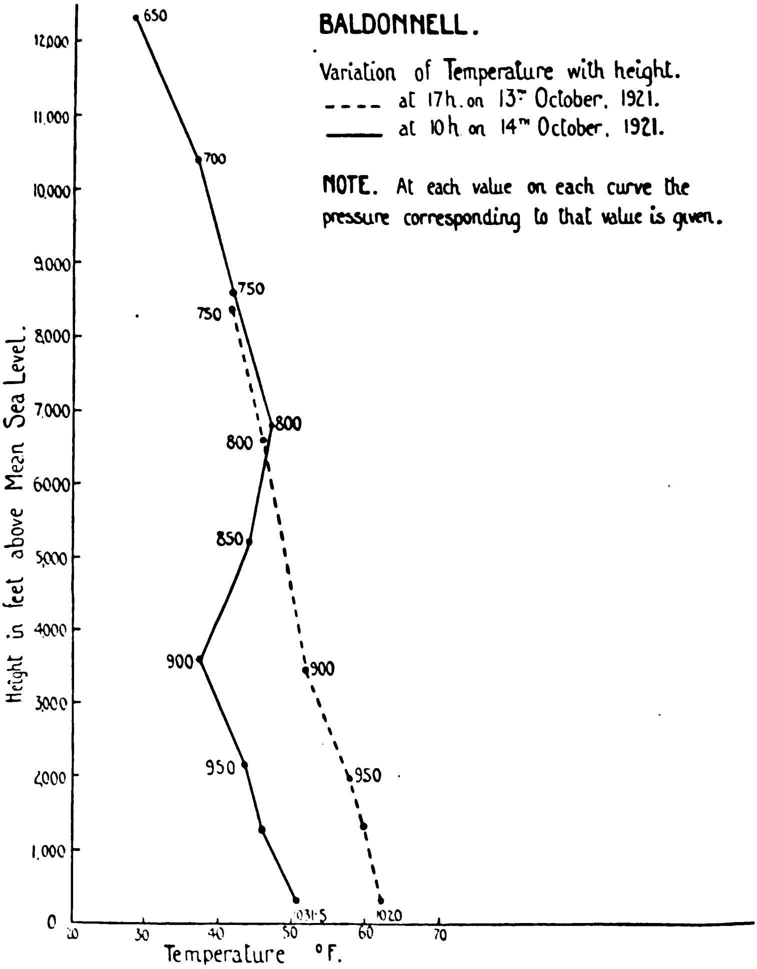
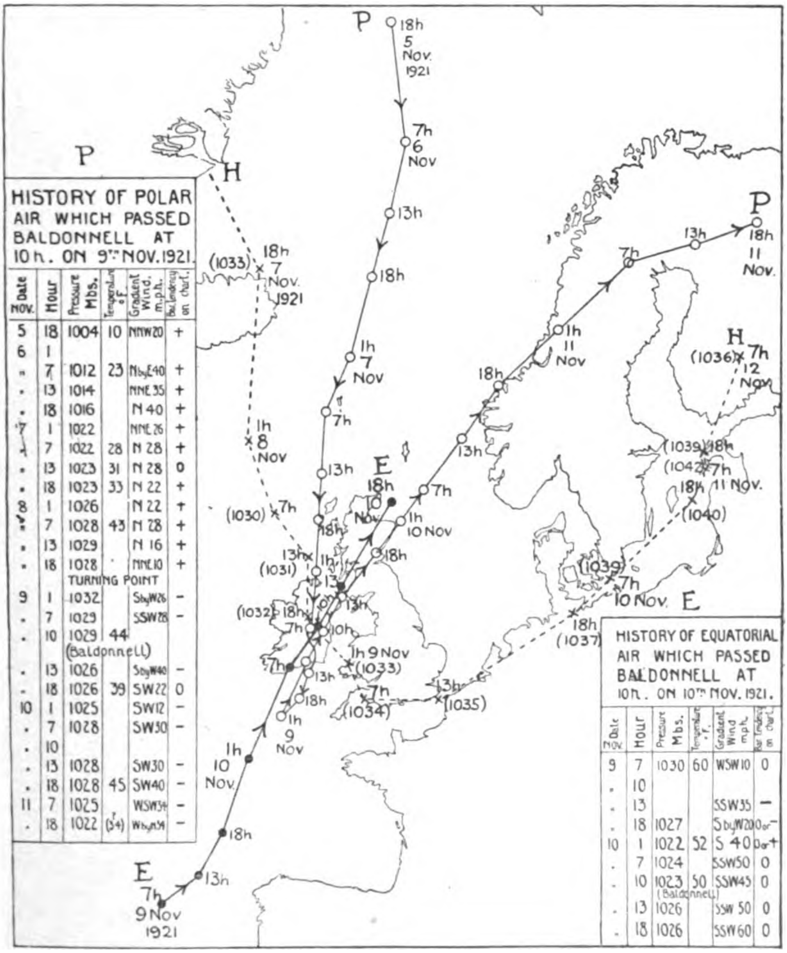


FIG. 5.

Examination of these cases led to the idea that here perhaps was the main cause of increases of pressure in our latitudes, namely, the insertion of a wedge of polar air under a widespread equatorial current, in such a way that a height h of equatorial air was replaced by a height $h + \delta h$ of polar air, the rest of the equatorial current being raised by an amount

8*h*. An example for which sufficient data were available was investigated. At Baldonnell at 17 h. on 13th October 1921 there was equatorial air all the way up, the sea-level pressure being 1020 mb. At 10 h. on 14th October, on the other hand, the sea-level pressure was 1031·5 mb. and up to about 4000 feet there was polar air; then there was a shallow transition layer, and above that, equatorial air, apparently of the same current as of the previous evening. It appeared that this wedge of polar air had forced its way under the equatorial and lifted the greater part of the latter by more than 200 feet. The features of this case are set out in Fig. 5. The next point that seemed to call for examination therefore was the history of a polar current.



HISTORY OF POLAR AIR WHICH PASSED BALDONNELL AT 10h. ON 9th NOV. 1921.

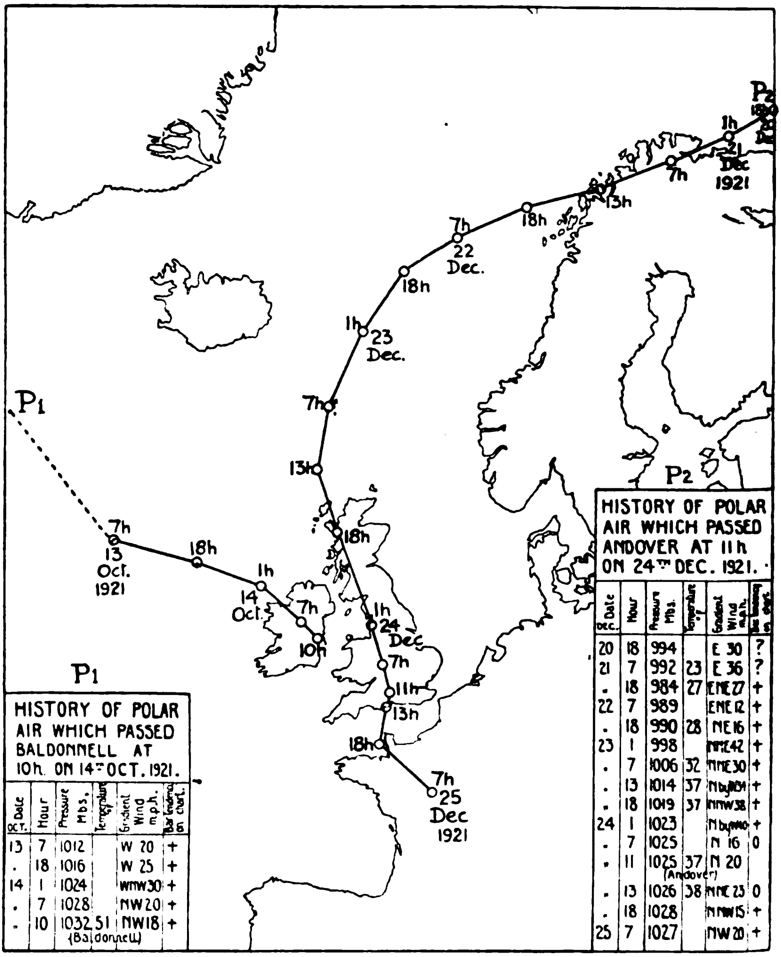
Date Nov.	Hour	Pressure Mbs.	Temperature °F.	Gradient Wind, m.p.h.	Bar. Tendency on chart.
5	18	1004	10	NNW 20	+
6	1				
"	7	1012	23	N by E 40	+
.	13	1014		NNE 35	+
.	18	1016		N 40	+
7	1	1022		NNE 26	+
.	7	1022	28	N 28	+
.	13	1023	31	N 28	0
.	18	1023	33	N 22	+
8	1	1026		N 22	+
.	7	1028	43	N 28	+
.	13	1029		N 16	+
.	18	1028		NNE 10	+
		TURNING POINT			
9	1	1032		S by W 26	−
.	7	1029		SSW 28	−
.	10	1029 (Baldonnell)	44		
.	13	1026		S by W 40	−
.	18	1026	39	SW 22	0
10	1	1025		SW 12	−
.	7	1028		SW 30	−
.	10				
.	13	1028		SW 30	−
.	18	1028	45	SW 40	−
11	7	1025		WSW 34	−
.	18	1022	(34?)	W by N 34	−

HISTORY OF EQUATORIAL AIR WHICH PASSED BALDONNELL AT 10h. ON 10th NOV. 1921.

Date Nov.	Hour	Pressure Mbs.	Temperature °F.	Gradient Wind m.p.h.	Bar Tendency on chart.
9	7	1030	60	WSW 10	0
.	10				
.	13			SSW 35	−
.	18	1027		S by W 20	0 or −
10	1	1022	52	S 40	0 or +
.	7	1024		SSW 50	0
.	10	1023 (Baldonnell)	50	SSW 45	0
.	13	1026		SSW 50	0
.	18	1026		SSW 60	0

FIG. 6.

Some trajectories of polar air were traced back from chart to chart by means of measured gradient winds. The remarkable characteristics in all cases were that the air left arctic regions with a low (sea-level) pressure and—at some early stage of its career—a high velocity. On its journey southward it eventually forced its way under equatorial air. Its pressure rose; also its temperature rose, and about half the change in temperature could be accounted for adiabatically; also its velocity diminished. In some cases it finally came to rest, then set off again towards the north-east, followed by an equatorial current; this time its pressure decreased and its velocity, as a rule, increased.



HISTORY OF POLAR AIR WHICH PASSED BALDONNELL AT 10h. ON 14TH OCT. 1921.

Date Oct.	Hour	Pressure Mbs.	Temperature °F	Gradient Wind m.p.h.	Bar tendency on chart.
13	7	1012		W 20	+
.	18	1016		W 25	+
14	1	1024		WNW 30	+
.	7	1028		NW 20	+
.	10	1032 (Baldonnell)	51	NW 18	+

HISTORY OF POLAR AIR WHICH PASSED ANDOVER AT 11h ON 24TH DEC. 1921.

Date Dec.	Hour	Pressure Mbs.	Temperature °F	Gradient Wind m.p.h.	Bar tendency on chart.
20	18	994		E 30	?
21	7	992	23	E 36	?
.	18	984	27	ENE 27	+
22	7	989		ENE 12	+
.	18	990	28	NE 16	+
23	1	998		NNE 42	+
.	7	1006	32	NNE 30	+
.	13	1014	37	N by NE 34	+
.	18	1019	37	NNW 38	+
24	1	1023		N by NW 40	+
.	7	1025		N 16	0
.	11	1025 (Andover)	37	N 20	
.	13	1026	38	NNE 23	0
.	18	1028		NNW 15	+
25	7	1027		NW 20	+

FIG. 7.

The trajectories labelled (P) in Figs. 6 and 7 are examples. In the former case the trajectory of a specimen of air in the overtaking equatorial current has been traced and is marked (E). Reference to Fig. 6 will show that the air (E) is actually gaining on the air (P) in their course towards north-east. This case is interesting from another point of view. On 5th November a high pressure appeared moving

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[2] Lamb, "Hydrodynamics," pp. 9, 10.

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of view. On 5th November a high pressure appeared moving

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[2] Lamb, "Hydrodynamics," pp. 9, 10.

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point of view. On 5th November a high pressure appeared moving south-southeastward from Greenland. On the following days its centre described the path marked (H) in Fig. 6. On this path I have marked also the pressure at the centre in so far as it could be estimated from the synoptic charts. These are the figures in brackets under the date and hour. It will be noted that there is a gradual increase of pressure from 1 h. or 7 h. on 8th November to 7 h. on 11th November, after which, so far as can be seen, the pressure again fell. The area enclosed by the 1030 mb. isobar showed up this feature even more prominently. The most obvious explanation of all these facts appears to be that a great patch of cold polar air, formerly lying in a more or less inert state over Greenland, started somehow to move south, pushed away or caused to retreat before it the surface layers of equatorial air previously in its path, and raised the remaining upper layers. This in the main would account for the rise in pressure. Up to a certain point in the subsequent retreat towards north-east, the equatorial current may have continued to pile up on it. Finally, however, the polar patch began to slide once again from under the equatorial air, and from that point pressure commenced to fall.

The features more or less common to these polar trajectories recalled the statement of Shaw and Lempfert[1] that motion under increasing pressure and with diminishing velocity did appear to take place sometimes, and that it must somehow be accounted for by an initial impulse. The important point is that the polar current seemed to expend some of its kinetic energy in displacing a certain thickness of another current and lifting the remainder by a few hundred feet.

It should be possible to apply some sort of numerical test to this statement. In the case of fluids in motion the equation of energy of the fluid occupying a given region may be written in the form[2]

$$\frac{d}{dt}(\mathrm{T}+\mathrm{V})=\iint p(lu+mv+nw)d\mathrm{S} + \iiint p\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)dxdydz, \quad . \quad . \quad . \quad (5)$$

where T and V denote the kinetic energy, and the potential energy in relation to the field of extraneous force, of the fluid which at the moment occupies the region in question, and where the first integral has to be taken over the whole bounding surface of the region and the second integral has to be taken throughout the volume. Further, the changes within the volume considered take place very approximately under adiabatic conditions, and if we call E the intrinsic energy of the fluid per unit mass we may write the volume integral as $-\frac{d\mathrm{W}}{dt}$, where

$$\mathrm{W}=\iiint \mathrm{E}\rho dxdydz$$

and where

$$\mathrm{E}=\frac{1}{\gamma-1}\left(\frac{p}{\rho}-\frac{p_0}{\rho_0}\right).$$

So that the equation of energy may be written—

$$\frac{d}{dt}(\mathrm{T}+\mathrm{V}+\mathrm{W})=\iint p(lu+mv+nw)d\mathrm{S} \quad . \quad . \quad . \quad (6)$$

which, being interpreted, means that the total energy which is partly kinetic, partly potential in relation to a constant field of force, and partly intrinsic, is increasing at a rate equal to that at which work is being done on the boundary by pressure from without.[1]

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[1] "The Life History of Surface Air Currents," M.O. No. 174, 1906.

[2] Lamb, "Hydrodynamics," pp. 9, 10.

Attempts were made to apply both of these forms of the energy equation to the case of the polar air of the trajectory shown in Fig 7. Rough values were taken as follows for the period of 24 hours from 18 h. on 6th November to 18 h. on 7th November 1921 :—

v changes from 35 to 25 m.p.h.
At surface p „ „ 1015 to 1025 mb.
„ „ temperature „ 25° F. to 35° F.

The leading edge of the polar current was assumed to be a wedge of angle 1/100. The results obtained were not quite what I expected, and I therefore mention only one, and that with some diffidence; it is that the wedge would have to extend back to a point where a vertical column within it would contain over 95 per cent of the mass of the whole column of atmosphere at that point. Practically, therefore, the whole thickness of the film of atmosphere must have moved southward, at least at the beginning; probably the forward area was detached later on.

One is tempted to speculate as to the origin of the initial impulse producing this movement. We can imagine loss of heat from polar regions resulting in the formation of cold "Highs." But these great air masses cannot go on indefinitely increasing in density at the expense of other regions, and yet remain in these latitudes. A point must be reached when the density of this film of atmosphere surrounding the earth becomes at these points too great for stability; sooner or later a fresh adjustment of pressure distribution over the globe has to take place and the whole mass of cold air (perhaps quite suddenly) shifts its position.

The pressure waves described by Simpson[2] as occurring in the Antarctic seem to bear out the probability of the existence of periodical adjustments of this kind.

It seemed appropriate at this stage to examine, in the light of the Bjerknes theory, a number of the trajectories in the "Life History of Surface Air Currents."[3]

The following were the conclusions drawn (relating to the surface air):—

(1) In polar air the pressure falls so long as it is being overrun by equatorial air.
(2) In polar air the pressure rises so long as it is undercutting equatorial air.
(3) In equatorial currents there is as a rule comparatively little change of pressure along a trajectory, at least until it is about to overrun polar air.

The last of these seems very remarkable and very important, namely, that in our latitudes so long as equatorial air extends right down to the surface the changes of pressure of any given mass of that air are nearly always slow and small in amount.

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[1] *Loc. cit.*

[2] "British Antarctic Expedition, 1910–13, Meteorology."

[3] *Loc. cit.*

Polar surface air, on the other hand, is subject to large and rapid pressure changes, its pressure depending largely on how far it has pushed its way under equatorial air.

4. Having regard to the shortness of the period from which the principal individual observations have been selected, the following statements are made with all due reserve but at the same time with an amount of confidence proportionate to the consistency within themselves of the observations examined. It is not claimed that all high pressures and all low pressures are to be explained in this way, but on the other hand the "Highs" and "Lows" which are not, may themselves be exceptions to the mean statistical relations.

(A) In our latitudes, *in high pressures* we should have—

either (1) a surface layer of polar air, and above it, equatorial air with the high stratosphere associated with more southerly regions. (Even the surface polar air will have had its temperature raised by adiabatic compression. The average height of the stratosphere in our latitudes in a " High " of 1033 mb. is 12 km., and this is about its mean height in latitude 30°);

or (2) equatorial air all the way up.

(B) In low pressures, on the other hand, we should have—

either (1) all polar air and a correspondingly low stratosphere. This would be the most frequent. (The average height of the stratosphere in our latitudes in a "Low" of 997 mb. is 8·6 km., which would also appear to be its mean height in about latitude 75°-80°);

or (perhaps) (2) equatorial air which has been "let down" by retreating polar air (steering surface);

or (near the centre) (3) a mixture of polar and equatorial air

Now all these help towards explaining the following known relations—

(1) The absence of correlation between pressure and temperature near the surface.

(2) The high positive correlation between pressure and temperature from 3 to 8 kilometres.

(3) The greater height of the stratosphere over high than over low pressure;

and A (1) and (2) and B (1) and (3) help to explain also

(4) The negative correlation between pressure and temperature in the stratosphere.

Put briefly, the features peculiar to most high pressures, namely, the warm troposphere, the high and cold stratosphere, need not have been developed in our latitudes by vertical motion or any other cause, but may simply be due to the fact that all but at most a shallow surface layer came from more southerly latitudes; in these southerly latitudes the peculiarities were already developed. Similarly the peculiarities of the low pressure are peculiarities developed by the polar air during its sojourn in arctic regions. With regard to low pressures one further remark may be made. In 1913, though the terms "polar" and "equatorial" were not then in use in the above sense, Gold[1] pointed out that the stratosphere is much lower and warmer on the west side of a cyclone than on the east side, but that somewhat farther to the east it is aga low and warm. This means that it is over those areas which contai most "polar" air that the stratosphere is low and warm.

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[1] *Meteor. Off.*, *Geophys. Mem.* No. 5, 1913, p. 121.

ADDENDUM, received December 16, 1922.

Since this paper was read it has occurred to me that, if the vi expressed therein are sound, there may be occasionally cases where of the equatorial troposphere is to be found actually above a certain thickness of air of the polar stratosphere. The case of 5th October 191 may be such an one. On that date *ballons-sondes* sent up from P and Uccle gave records which were in good agreement, and of which outstanding features in the latter case were—

(1) A fall of temperature from 281 a. at ground level to 22 8·6 km.;
(2) Approximately isothermal conditions up to 11 km. (tempe 227 a.);
(3) Another fall of temperature to 218 a. at just under 15 km.
(4) Little change thereafter; 221 a. at 21·4 km., where the r ceased.

Pilot-balloon ascents at Copenhagen and Uccle indicated a definite discontinuity of wind at a height of 11 kilometres. Just below this level the mean wind was Easterly, about 15 m/s. From 11 to 15 km. at Copenhagen the mean wind was WSW, 2 m/s; at Uccle it was ESE, 5 m/s.

The available upper air data, together with the synoptic charts, make it reasonably certain that over Belgium there was polar air up to a height of 11 kilometres, the polar stratosphere commencing at 8·6 kilometres. [The Deutsche Seewarte at Hamburg, with an ascent extending up to 10·1 km., placed the base of the stratosphere at 8·85 km.]. On the other hand, it is at least probable that above 11 km. there was air of equatorial origin which may have arrived either by way of the north side of an extensive anticyclone on the North Atlantic, or more directly from the direction of the Eastern Mediterranean. Of this air the part from 11 to about 15 km. would be of an equatorial troposphere; the part above 15 km. would be the equatorial stratosphere.

DISCUSSION.

Mr. C. K. M. Douglas in a written contribution said: I am in agreement with the view expressed by Mr. Goldie that the explanation of the temperature distribution in cyclones and anticyclones is to be sought chiefly in the horizontal movements. I have traced back a considerable number of trajectories of gradient wind on Atlantic charts from different parts of cyclones which crossed the British Isles, and find that the air even in the warm sector often proves to be of polar origin if followed back far enough, though it has been warmed over the sea for much longer than the air in the coldest parts of the cyclone. Air of truly equatorial origin is often found far out on the south or east flank of the cyclone, and sometimes over the whole warm sector up to the centre, and in these cases upper air temperature is probably high over the centre. On February 17th, 1919, temperature at 3 km. over N.E. France was 8° F. above the normal, close to the centre of a deep cyclone. The current had come from beyond the Azores in the preceding 48 hours, with little change of surface pressure along its path. Upper air temperature was also above normal at Utrecht on July 6th, 1922, only 300 miles from the centre of a cyclone unusually deep for the time of year. On this occasion surface pressure had fallen considerably along the trajectory in the preceding 24 hours, which seems an exception to Mr. Goldie's rule, but it is not certain that the current in this instance was of truly equatorial origin. I think it would be worth while to trace this current back further than is possible from the *Daily Weather Reports*. It is thus evident that cyclones are not always cold even in Western Europe, while in the United States they are not even cold on the average.[1]

A fact to be taken into account is the very low relative humidity in the upper air sometimes found in anticyclones. This could be explained by a gradual descent during a long period, chiefly in latitudes 30° to 40°, which would usually predominate over any temporary ascent due to polar air thrusting in below.

In connection with the very interesting data in Fig. 6, it is perhaps worth adding that on November 10th, 1921, upper air temperature was much higher at Leuchars than at Andover, which was doubtless noted by Mr. Goldie but which does not appear in print.

Col. E. **Gold** said that he was very interested in Mr. Goldie's deduction that anticyclones were constituted of equatorial air. He himself had suggested some ten years ago that many anticyclones might be due to the bulging of the equatorial stratosphere northwards (or southwards), but Mr. Goldie had gone a good deal further and attributed the anticyclone even in its lower layers to equatorial air. This was an important fact. In connection with temperatures in anticyclones one naturally recalled to mind that Hanzlik divided anticyclones into two kinds—those which were warm and moved slowly and those which were cold and moved fast. It would be very interesting when more observations were available to go further into that aspect of temperature distribution in anticyclones. This paper indicated how important are actual observations of upper air temperature and, in the absence of actual upper air observations, the nearest approximate information from the surface conditions; which in the case of inland stations was the midday or maximum temperature. This was one of the reasons why the International Telegraphic Commission had arranged for maximum temperatures to be included in the telegraphic reports from inland stations.

Mr. J. E. **Clark** asked Mr. Goldie to explain the statement on p. 14 in which he said that in polar air the pressure falls so long as it is being overrun by equatorial air and rises so long as it is undercutting equatorial air. It apparently depended on a relative velocity and seemed to be the same thing said in a different way.

Mr. F. J. W. **Whipple** discussed the significance of the correlation coefficients set out by Mr. Goldie in Table I. of the paper. In the computation of any one of these coefficients comparison was made between pressure and temperature without explicit reference to height. The pressure differences are mainly due, however, to height differences; for such a range of pressure as from 950 mb. to 750 mb. is not met with at a fixed height. In fact the correlation coefficients indicate how closely temperature is determined by height in polar air and in equatorial air. That being so, it is remarkable that the coefficients found by Mr. Goldie are not higher. The unwary reader might be inclined to think that the correlation coefficients were on the same footing as those which Mr. W. H. Dines had obtained by comparing pressure and temperature at a fixed height. In Mr. Dines's comparisons the fundamental fact was that at any level except near the ground the transition from high pressure to low pressure was associated with the transition from high temperature to low temperature. Mr. Dines attributed this association to dynamical causes and especially to the vertical movement of the air, whereas Mr. Goldie emphasised the importance of the geographical causes which determined the characteristics of air arriving from different parts of the globe. The point which Mr. Whipple wished to make was that the correlations of Table I. did not strengthen the general argument of the paper.

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[1] Gregg, W. R. "The vertical temperature distribution in the lowest five kilometres of cyclones and anticyclones." *Washington, D.C., U.S. Dept. Agric., Monthly Weath. Rev.*, **47**, 1919, pp. 647-649.

Sir NAPIER SHAW said that he was glad to see the subject taken up in a definite way. Mr. Whipple had drawn attention to the meaning of the correlation coefficient in the tables. He was not quite sure what would be the effect of allowing a wide range of height in computing correlation coefficients between the pressure and temperature. Pressure and temperature usually fell together with increase of height, but there were occasions when the temperature increased with height, and the correlation for a definite level would be spoiled by associating different levels in one coefficient. The two things were equally worth investigating. He did not want to deal with the details but wished to speak of general questions. First of all, Mr. Goldie seemed to recognise polar air when he saw it, but had not told what the label is. Is it air coming from the north, or east, or north-west? The winds are not the same in the upper levels as at the surface. A most interesting question was, whether the polar front really extends up to the top of the atmosphere or is limited to air crawling about near the bottom? It would be well to have the definition of polar air stated. Mr. Goldie's diagrams associated the names polar and equatorial with curves of height-temperature of certain shapes in certain relative positions. On that plan what would be classed as polar air in one locality might be equatorial air with reference to another part of the globe. If you took the corresponding normal curves for successive regions from the equator to the pole, they would show a gradual transition from the curve of one type to the curve of the other type. The changes are characteristic of the differences in the curves as you go farther north. Are you on that account going to call the curves of latitude 40° polar and those of latitude 30° equatorial? The difference between them might be quite relative. In the average curves the changes in the characteristics are continuous all the way through. Whether there is discontinuity on individual occasions he did not know. Sir Napier Shaw was interested in the curve in which the polar air underlies the equatorial air. The section consisted of three parts in Fig. 5: one part from the surface to 900 mb., a second 900 to 800 mb., and a third 800 to 650 mb. In discussing the observations off the Newfoundland Banks, Mr. G. I. Taylor derived this 800 to 900 mb. inversion from the effect of cold surface upon "equatorial" air. A zigzag curve like Mr. Goldie's was produced when the surface-air got warmer after being cooled. Thus one could get similar curves by different processes. It was very difficult to make quite certain of the process by looking at the final result. Taking, for example, the present case, Mr. Goldie suggests that the increase of pressure in the curve of Fig. 5 is due to the slipping of cold air along the surface. The speaker knew only one case in which the process has been actually traced: that represented by the two glass models in the Meteorological Office—July 27th and July 29th, 1908. There the introduction of the cold air was apparently at the tropopause where it showed as an inversion. Putting extra stuff into the column at any level increases the pressure at the bottom. Thus the effect which was represented as underpinning the bottom might be produced by introducing air at the top of the troposphere. There was another point to which he wished attention to be drawn. The effect of addition of heat was introduced into equation 4 in the form of a term $-\frac{1}{cp}.\frac{dQ}{dt}$; Mr. Goldie was then rather careful to leave it out, and one wondered what the effect of that treatment was. The term was really always there, and at present nobody knew what its magnitude was. Dealing with normal values, if a portion of the atmosphere throughout the whole thickness changed its latitude there would be a change of temperature corresponding with change of pressure. But there would also be a change due to radiation represented by the term which had been omitted. We ought to find out the extent of this change. On page 11 was said "it appeared that this wedge of polar air had *forced* its way under the equatorial and lifted the greater part of the latter by more than 200 feet." That form of expression seemed to endow the polar air with a personality that it did not possess. The speaker could understand that it *found* its way, but he could not understand that it forced its way. It was itself equally subject to forces and must be taken as part of a general system.

Mr. L. F. **Richardson** thought the paper an excellent illustration of the remark that the combination of theory and observation is more interesting than either separately. When one sees Lamb's *Hydrodynamics* on the same shelf as a volume of observations one would like to see them brought into harmony with one another.

Mr. Goldie had concluded that the polar and tropical air-masses move solidly, carrying their stratospheres with them. This view furnished a simple explanation of the varying height of the tropopause. But was it compatible with the known variation of wind-speed with height? In his first paragraph Mr. Goldie had made a statement which might be taken to mean that vertical motion was unimportant. But in mechanics the importance of a displacement was not measured by its length alone, but by length and force conjointly. The speaker submitted that the paper did not really imply that vertical motion could be ignored. For the supply of energy to the atmosphere is mostly by the sun's heat absorbed at its lower limit. And, as Sandström had pointed out, if the steady heating of a gas is to maintain it in motion, the heat must be applied at the bottom and not at the top; just as in the domestic hot-water system the boiler must be on a lower floor and not in the attic. Thus vertical circulation appeared to be necessary if solar heat were to be converted into wind-energy.

Mr. Goldie had included the three forms of energy T, V, W together in one bracket. The problem would be simplified if the internal heat energy W could be separated from T and V. It was not obvious that such a separation could be effected. But the speaker had given a proof that the ordinary adiabatic relation of pressure to temperature was correct whatever kinetic energy were produced during the change.[1] In view of this, it appeared that the change of surface pressure from 1015 to 1025 mb. which Mr. Goldie mentioned would have corresponded to a temperature change of about 1° C. if the motion had been adiabatic, whereas the observed change was 5°·5 C. This fact was striking, because the theory of the polar front assumed that air moved nearly adiabatically. [Note added December 3rd. But the motion may have been much more nearly adiabatic at a height of say 1 km.] He trusted that these remarks would not be thought to be a disparagement of the paper, which was a most interesting one.

Mr. D. **Brunt** suggested that a fuller explanation should be given of the examination of the trajectories given by Shaw and Lempfert in the light of the Bjerknes theory, in view of the striking nature of some of the results deduced by Mr. Goldie. He would like to query whether Mr. Goldie had proved that a cyclone is unsymmetrical. None of the observations analysed had been made in the central part of a cyclone, and even on the revolving fluid theory of a cyclone it is not necessary to suppose that the symmetry would extend indefinitely outward from the centre. He congratulated Mr. Goldie on his very stimulating paper.

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[1] *Weather Prediction by Numerical Process.* Cambridge Press, ch. 4/5/0.

Mr. A. H. R. **Goldie**, replying to Col. Gold's remark about cold anticyclones moving fast, said that the anticyclone of Fig. 6 was a rather cold one; in fact it was one in which the polar air extended up to quite a considerable height. Mr. Whipple's point about the size of the correlation coefficients in relation to those of Mr. W. H. Dines ought to be emphasised, for he was afraid that here and in some other parts the paper had perhaps been condensed too much. These correlation coefficients were introduced to answer the question, "How closely can temperature be written down as a function of pressure in equatorial and in polar air respectively and altogether irrespective of height?" The leading fact shown by the coefficients was that in equatorial air temperature is much more definitely a function of pressure than it is in polar air. Sir Napier Shaw had referred to the difficulty of recognising polar air. The speaker, realising this, had endeavoured not to lose trace of the polar front at the surface from day to day. The four daily synoptic charts had been studied, for it was certainly difficult, dealing with an isolated map, to say this is polar or this is equatorial air. The trajectories he regarded as representing the motion of, say, the first kilometre of the air from the surface upwards. With regard to what Sir Napier Shaw said about polar and equatorial air being relative terms and about the change of the temperature-pressure curves from one extreme in the matter of shape to the other extreme as one moved from the equatorial regions to the poles,—he suggested that this might be due to the fact that in moving northward one encountered a continually increasing percentage of instances of polar air. Mr. Richardson's remarks were interesting and suggested points that would require some time to examine. In particular Mr. Richardson had said that the paper did not really imply that vertical motion could be ignored. This was correct. His other remark, that in mechanics the importance of a displacement was not measured by its length alone, but by length and force conjointly, went to support the view taken in the paper, namely, that it was simpler to account for various facts by horizontal movement of the air than by assuming vertical motion on a large scale. There were great difficulties in imagining considerable vertical motion over an area comparable with that of a cyclone or anticyclone. The speaker, by comparing the rate of change of pressure at a given point with the rate of change of pressure in a given moving mass of air, had made certain calculations with a view to finding the largest probable values of the mean vertical motion over such an area. An apparently favourable case was found in the *Life History of Surface Air Currents.* This was the case of the formation of a depression on October 7th to 9th, 1903. Even here the mean vertical velocity could scarcely have reached 0·01 kilometre per hour or about 1 kilometre in four days. Other cases investigated gave even smaller mean vertical motions.

THE MANILA TYPHOON OF MAY 23, 1922.

By Rev. JOSÉ ALGUÉ, S.J., Hon. Mem., Director, Philippine Weather Bureau.

[Received September 28—Read November 22, 1922.]

The official report of this typhoon given to the press, prepared by Rev. José Coronas, Chief Meteorological Division, runs as follows:

"The first typhoon of the season traversed the central part of the Philippines in a north-westerly direction on May 20 to 23, the centre having passed practically over Manila on the morning of the 23rd. Fortunately, however, for the city, the typhoon was here very abnormal as far as the winds were not very strong, even when the barometer was rising very rapidly after the passing of the vortex. Hence, Manila missed the worst of the storm, and, although the barometric minimum in the present case, 742·3 mm. (29·22 inches), was somewhat lower than in the two previous typhoons of August 31, 1920, and July 4, 1921, yet the damage done was much smaller, the maximum velocity of the wind, even in a few isolated gusts, not having been higher than 60 miles per hour.

"The centre, as just stated, passed practically over Manila, though a little to the west, as was shown by the winds veering very rapidly from NNW and N to E and S in less than two hours, and by the relative calm which was clearly observed for about 23 minutes, from 8.01 to 8.24 a.m.

"Our weather map for 2 p.m. of the 19th showed the typhoon over the Pacific about 200 miles to the east of Mindanao. The centre passed near Surigao to the north between 5 and 6 p.m. on the 20th, and at 6 a.m. on the 21st it was situated over the northernmost part of Cebu Island, near long. 124° E. and lat. 11° N., moving approximately to N.W. by W. If the typhoon had not changed its direction, it was heading for Mindoro; but a slight inclination of the track to the north caused it to go from Romblon to Marinduque, and from Marinduque to Manila. After striking Manila, however, it took again its former direction to N.W. by W., thus entering the China Sea near to the south of Iba.

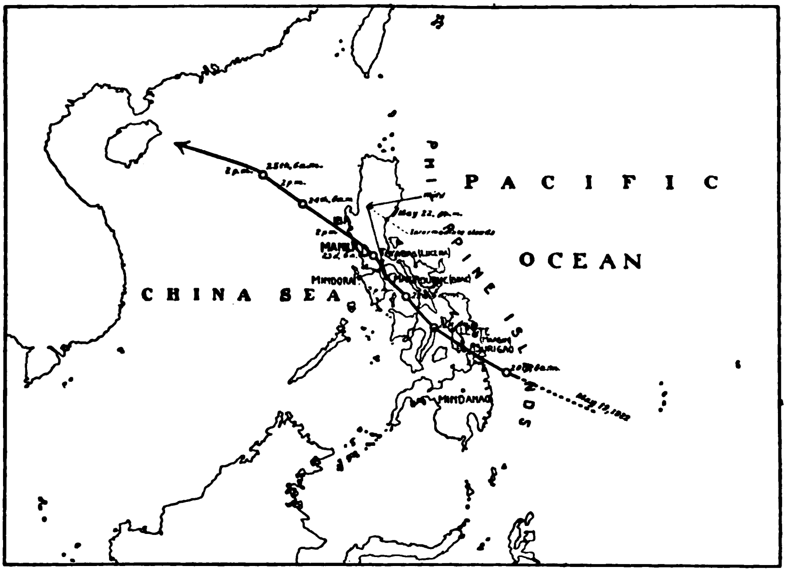
"The following are the most important barometric minima recorded in the Philippines in this typhoon:

Surigao . .	744·95 mm. (29·33 inches) at 5.45 p.m. of the 20th.
Maasin, Leyte .	746·90 mm. (29·41 inches) at 10.50 p.m. of the 20th.
Romblon . .	746·90 mm. (29·41 inches) between 9 and 10 a.m. of the 22nd.
Boac, Marinduque.	741·90 mm. (29·21 inches) at 8.30 p.m. of the 22nd.
Lucena Tayabas .	747·70 mm. (29·44 inches) at 1.15 a.m. of the 23rd.
Sta. Cruz, Laguna .	746·10 mm. (29·37 inches) at 4.50 a.m. of the 23rd.
Manila . .	742·30 mm. (29·22 inches) at 8.20 a.m. of the 23rd.
Iba . . .	747·29 mm. (29·42 inches) at 3.0 p.m. of the 23rd.

"While the rate of progress of the typhoon between Surigao and Maasin was 8 or 9 miles per hour, it decreased later to such an extent that from Romblon to Boac the storm moved at the rate of only 5·6 miles per hour. When nearing Manila, it increased again to about 8 miles per hour; and from Manila to Iba the rate of progress was even greater than 10 miles per hour.

"According to the observations at hand it would seem that the typhoon filled up on the 26th in the China Sea east of Hainan."

May I add a novel experiment made in connection with this typhoon? On the 22nd, before the vortex crossed Manila as stated in the report, I was accidentally in our mountain station in Baguio, and I wanted to ascertain, as much as possible, the position of the centre through the wind and cloud movements. For that purpose I took two photographs



of the wind vane and of the sky, with an interval of ten seconds, and on the same plate. In the map of the typhoon track there is the direction of the wind as shown by the arrow of the wind vane and the direction as shown by the displacement of clouds during the interval between the two exposures. No doubt this method may be used for similar purposes, with success, with an ordinary camera or kodak. One thing is to be borne in mind, that, owing to the height of the station, 4777 feet above the mean sea-level, winds and cloud directions are less convergent than in lower levels.

THE METEOROLOGICAL SECTION OF THE INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION.

By Sir NAPIER SHAW, F.R.S.

[Read at a Meeting of the Society, November 22, 1922.]

THE INTERNATIONAL RESEARCH COUNCIL.

As the duration of the war drew on from six months, a year, two years and more, towards four years, the Academies of Science of the allied countries became solicitous about the future of scientific work on an international basis. A conference was held in the Rooms of the Royal Society of London in October 1918. It arrived at a resolution :

> 1. Aussitôt que les circonstances le permettront, les conventions relatives aux Associations scientifiques internationales seront, conformément aux Statuts ou règlements propres à chacun d'elles, dénoncées par les groupements compétents des Nations en guerre avec les Empires centraux.
>
> Les nouvelles Associations reconnues utiles au progrès des sciences et de leurs applications seront établies, dès maintenant, par les Nations en guerre avec les Empires centraux, avec le concours éventuel des neutres.

A second conference was held in Paris in November 1918, at which a project was mooted for the establishment of an International Research Council; Brussels was chosen as its legal seat. Its operations in respect of finance and other legal aspects were to be conducted in accordance with Belgian law. In pursuance of this decision the first plenary sitting of the International Research Council was held at Brussels in July 1919, and a body of statutes was adopted on the 28th of that month.

The statutes are twenty-five in number divided into eight chapters. The first chapter sets out the objects of the Council; the second the seat of its governance; the third lays down the conditions of admission of countries to the Council; the fourth provides for the administration of its business; the fifth contains the regulations for an Executive Committee consisting of four persons (a president, two vice-presidents, and a secretary) to conduct the business of the Council in the intervals between general assemblies; the sixth regulates the aforesaid general assemblies to be held as a rule every third year; the seventh chapter prescribes the pecuniary contributions and the voting rights of the several countries adhering to the Association, graded according to the numbers of their inhabitants; and the eighth limits the duration of the convention to twelve years from January 1, 1920, makes provision for its renewal, and also for changes in the statutes.

The following extracts from the statutes may be quoted :

I. OBJECTS OF THE INTERNATIONAL COUNCIL.

The purpose of the International Research Council is—

(*a*) To co-ordinate international activity in the different branches of science and of its applications.

(*b*) To promote, in accordance with Article 1 of the resolution of London (October 1918), the creation of international associations or unions, which are considered useful for the progress of the different branches of science.

(*c*) To direct international scientific activity where suitable associations do not exist.

(*d*) To enter, by suitable means, into relation with the Governments of the countries adhering to the scheme, in order to promote the study of questions of which they are cognisant.

III. ADMISSION.

4. A country may adhere to the International Research Council or to the Associations which are connected with it, through its National Academy, through its National Research Council, through other similar national institutions, or through its Government.

5. The statutes of associations connected with the International Research Council must be approved by the Council.

Whether, in accordance with 4, the same country could adhere in two capacities is not stated.

The *Year-Book of the Royal Society*, 1922, p. 131, summarises the proceedings of these conferences and assemblies as follows:

An International Research Council was formed for the purpose of facilitating international co-operation in scientific work, and promoting the formation of International Unions in different branches of science.

The affairs of the International Research Council are managed by an Executive Committee, the General Secretary of which is Sir Arthur Schuster, For.Sec.R.S.

Under the auspices of this Council, International Unions have been formed for Astronomy, Geodesy and Geophysics, Chemistry, Mathematics, and Radio-Telegraphy, and provisional statutes have been drawn up for International Unions in Physics, Geology, Biological Sciences, and Geography.

The Royal Society, acting as the National Academy of Great Britain, appoints the British delegates to the meetings of the International Research Council.

NATIONAL COMMITTEES.

For each International Union a National Committee either has been formed, or is in process of formation in accordance with Statute 1, Clause 2, of the International Research Council. The functions of these National Committees are defined in the statutes of the various Unions. In general, they are the promotion of the branches of science with which they are concerned more especially as regards international requirements, the appointment of delegates to represent the United Kingdom at meetings of the Unions, and the initiation of proposals or questions for discussion at such meetings.

National Committees of the United Kingdom for Astronomy, C and Geophysics, Mathematics, Physics, Radio-Telegraphy and Geograph been constituted by the Council of the Royal Society.

The members of the Executive Committee of the Intern Research Council are:

President—Emile Picard, Sécrétaire perpétuel de l'Académie des S 25, quai Conto, Paris (6).

General Secretary—Sir Arthur Schuster, D.Sc., F.R.S., Foreign Sec the Royal Society, Yeldall, Twyford, Berks.

Members—G. Hale, Director of the Mount Wilson Observatory, I California, U.S.A. G. Lecointe, Director of the Royal Observatory, of the Royal Academy of Belgium, Avenue Circulaire, 1, Uccle. V. Senator, President of the Accademia dei Lincei, Professor of Math Physics at the Royal University of Rome, via in Lucina, 17, Rome.

At a meeting of the Council held at Brussels this year on July 25 and four succeeding days, it was decided to enlarge the Executive Committee by the addition of a representative from each of the separate Unions. Twenty countries have now joined the International Research Council. Some others have joined or desire to join the Geodetic Section alone.

THE INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION.

It will be noted that under the auspices of the International Research Council there are a number of separate Unions each of which manages its own affairs, in accordance with statutes which must have received the approval of the Council.

Within each Union are separate Sections with separate Bureaux of President, Vice-Presidents, and Secretary, and an Executive Committee. The Union with which we are specially concerned is the Union for Geodesy and Geophysics which comprises the following sections: (1) Geodesy, (2) Seismology, (3) Meteorology, (4) Terrestrial Magnetism and Electricity, (5) Oceanography, (6) Vulcanology. A new section (7) for Land Hydrography was constituted at Rome in the present year.

For each Union there is supposed to be in each country a National Committee. The National Committee for Geophysics and Geodesy in this country is appointed by the Royal Society as follows:

Chairman—Colonel H. G. Lyons. *Members ex officio*—The Astronomer-Royal, the Director of the Meteorological Office, the Director-General of the Ordnance Survey, the Hydrographer of the Navy. *Other Members appointed by the Royal Society, till December* 31, 1924—Dr. C. Chree, Sir Richard Glazebrook, Col. E. H. Grove Hills,[1] Mr. J. H. Jeans, Sir Joseph Larmor, Sir Napier Shaw, Prof. H. H. Turner; *till December* 31, 1927—Prof. S. Chapman, Mr. A. R. Hinks, Prof. H. Lamb, Sir G. Lenox-Conyngham, Col. H. G. Lyons, Sir Arthur Schuster, Mr. G. I. Taylor, Mr. C. T. R. Wilson. *And the following representatives of other bodies:*

Of the Royal Irish Academy: Prof. J. Joly, Dr. A. A. Rambaut.
Of the Royal Society of Edinburgh: Dr. C. G. Knott,[1] Dr. A. C. Mitchell.
Of the British Association: Dr. J. E. Crombie, Mr. J. J. Shaw.

Some of the adhering countries divide their national committees into separate sections corresponding with those of the Union. In this country, so far, we have not done so. The United States, for example, has a National Committee of 64 members, of whom 23 form a Section for Meteorology, other 24 Terrestrial Magnetism and Electricity, and Physical Oceanography respectively. France has a National Committee of 124 members, of whom 49 constitute a Sectional Committee for Meteorology. The Italian Committee for the Meteorological Section comprises 22 members. Our National Committee includes only 25 members to deal jointly with all the seven subdivisions or sections.

THE METEOROLOGICAL SECTION AND ITS PROGRAMME.

The new feature of this international association for the advancement of science is that there is a certain amount of money placed at the disposal of the sections. Each country adhering to the Union makes a contribution thereto, and the Union divides its funds among the sections. The sums which were announced as being at the disposal of the Meteorological Section were an accrued sum of 32,542 francs, and a prospective income of 22,400 francs a year for three years. These sums are subject to some modification in consequence of the variations of the exchange and the decisions of various countries concerning membership.

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[1] Since deceased.

When the Section for Meteorology was constituted at Brussels I was appointed President of the Sectional Bureau; Monsieur Angot, Vice-President; and Dr. C. F. Marvin, Secretary. As the time of the proposed meeting in Rome drew near I was appealed to by the Secretary of the Union to compile a programme for the Section. One of the regulations is that the subjects for consideration must be submitted by the respective national committees.

A Programme of Research on an International Basis.

An obvious difficulty about providing a programme that might reasonably come within the purview of a Council of Research, is the peculiar nature of meteorology as a science. Research in meteorology in its best sense means the co-ordination of material derived from various parts of the world at various times, and its application to our enlightenment upon the structure of the atmosphere and the changes which occur in it. In order to discuss any question which depends upon the structure of the atmosphere, information is required about it from all parts of the world, at all levels, and at all times and seasons. It is easy to say that such a demand is extravagant and preposterous because obviously it cannot be satisfied. In spite of that criticism it must still be pronounced indispensable, for in so far as the information is lacking it has to be guessed by the researcher, or in the alternative it has to be regarded as unimportant for the immediate object. It is a very sorry alternative because it means basing the hypothesis of its insignificance upon ignorance of the facts, which is the worst possible form of science. If any meteorologist wants to go a-guessing let him begin by estimating the volume of the meteorological scrap-heap that has accumulated in the last hundred years through guessing at facts and guessing wrong.

If, therefore, any institution would encourage research in meteorology it should pay attention to two requirements, first of all the filling of the gaps in our knowledge of the facts of the atmospheric structure, and secondly the reviewing, or shall I say the parading, of the facts which are available to stimulate productive discussion by those minds which are capable of passing a vast collection of facts through a recognised deductive mill, or, still more difficult, of making a true inductive scientific picture out of the facts which of themselves, at the very best, must be of the nature of a coarse mosaic.

The Collection of Data.

As regards the collection of data a special point for consideration arises in connection with meteorology. It is not altogether a new departure; we are quite familiar with international organisation for collecting suitable data. Since 1853 the established meteorological institutions of the world have been united in the endeavour to collect such ordinary meteorological observations from the sea as are suitable for the study of the structure of the atmosphere; and since 1873 that spontaneous union has been extended to include all such observations from the land. These include observations, at the surface, of pressure, wind, temperature, humidity, precipitation and weather, and, above the surface, of the forms, direction and motion of clouds. The measurement of the height of clouds has also been organised on an international basis. Since 1896 observations of the upper air have been similarly cared for. It would be little less than absurd to start again in 1922 from the position of our predecessors in 1853 and do it all over again. But any one who has endeavoured to put together the available facts of meteorology for the whole globe must have become aware how every effort is frustrated for lack of observations—either of ordinary observations from some special localities or still more frequently of special observations from many localities. In illustration of what I mean I may note that the first demand of the new Norwegian School of Meteorologists was for five hundred ordinary stations and some special ones, round about latitude 60°, for the adequate exploration of the polar front; and at the same time Professor van Bemmelen bewails the lack of observations in the intertropical regions. Now we can safely leave the extension of information by means of ordinary observations to the established agencies, who are already agreed as to methods, and who want the information for their immediate practical purposes.

THE GAPS IN OUR KNOWLEDGE.

But consider some other gaps in our knowledge:

1. The lack of observations of temperature and wind-velocity in the upper air over vast areas of sea, over deserts or inhospitable regions which have their share in the control of the atmospheric circulation, although they are quite beyond the ordinary reach of meteorologists attached to established institutes or observatories.

To get these we must obtain new sources of observation by persons who are more favourably placed than the ordinary meteorologist.

2. How extremely ill-informed we are about the actual detail of the process of convection which we know to be an essential part of the formation of rainfall. We do not even know whether convection proceeds by general mass-movement or per quantum, and, if per quantum, what the size of the quantum is. Which of all the meteorological observers of the world pays special attention to this question?

3. What is the immediate, and what the ultimate, effect of an active convection upon the surrounding atmosphere, and what is the true meaning of the relation between pressure and temperature, which Mr. W. H. Dines has found in the English observations of the upper air, and which exists in like manner in Canada and at the Equator?

I have read a good deal about what it does not mean, and gather that some people think it means nothing at all. They are satisfied that it is only what we ought to expect from what we know of the physical properties of the atmosphere. Let me remark that, whether we expect it or not, we have to put up with it; but the really interesting question is what it means: whether in fact isobars in the atmosphere are also isotherms, or, to put the question in the language of V. Bjerknes, is the atmosphere normally and generally barotropic? or if not, is the baroclinic condition general or local?

4. Next consider our ignorance of the rôle of radiation in the sequence of weather. Recently our knowledge of solar radiation has been much extended, particularly in the United States, in Sweden, and in Switzerland. Mr. W. H. Dines has also done much lately in terrestrial and atmospheric radiation. It used to be generally assumed that air rose over the equator, drifted to the tropics, and having lost its heat by radiation came down again then and there. I believe that to be a fairy tale, but to prove it so requires the examination of the contributions which I have mentioned, and some more.

5. Next we may note the old vexed question of the impairment of the visibility of the atmosphere. What is that condition which I will call *nebula*? It prevents our seeing, yet we cannot recognise it as *nubes*, a cloud. Is nebula water condensed on hygroscopic molecules, or is it partly or wholly dust? It is an interesting question, and the Committee for Atmospheric Pollution has recently brought forward an apparatus for abstracting samples of the dust and nailing them to a microscope-slide. We have therefore made possible a definite step in the solution of this question, and have produced a method which can be employed in other atmospheres than those of this city or country.

6. And finally, there is the vexed question of the composition of the atmosphere above 100 kilometres, which has now become of great importance in relation to the aurora through the work of the Norwegian geophysicists, Birkeland, Störmer, Vegard, and Krogness. Is hydrogen the main constituent or is it not?

These six questions are all of living reality and ought to be solved, but not one of them can be definitely assigned as the recognised duty of any existing Meteorological Service. They were therefore brought before the Meteorological Section of the International Union by the British National Committee at the suggestion of a Committee of the British Association as questions in the solution of which the Section might assist and which might otherwise linger on unsolved, being left to the precarious attention of the leisure of men otherwise occupied.

The questions proposed by France were of a more general character:

(1) The different sorts of thunderstorms and more generally the electrical phenomena of the atmosphere.
(2) The transparency of the atmosphere and its optical phenomena.
(3) The different sorts of clouds.
(4) Forecasting weather, and particularly the method of tendencies or the method of isallobars.

The Italian Committee added a further question, namely, the necessity for presenting normals of meteorological data according to modern statistical methods.

These, and a few subjects added with permission of the Section by some of the meteorologists present, furnished the scientific programme of the meeting.

THE PROCEEDINGS AT ROME.

After a ceremonial session of both Unions in the Hall of the Horatii and Curiatii of the Capitol in the presence of His Majesty the King of Italy, separate meetings of the Astronomical Union and the Geodetic and Geophysical Union were held, and then the Sections met separately; they united again in meetings of the respective Unions at the close of the proceedings.

The meetings of the Section were open to any delegates who were present. In the Minutes I find the following names mentioned—in some cases I have had to guess their country:

Australia.—The Rev. F. Pigot, S.J.

Belgium.—Commandant J. Jaumotte (Uccle).

France.—Colonel E. Delcambre (Paris), M. G. Bigourdan (Paris).

Italy.—Prof. G. Alfani (Florence), Prof. A. Artom (Turin), Prof. A. Bemporad (Naples), Prof. L. de Marchi (Padua), Prof. F. Eredia (Rome), Prof. P. Gamba (Pavia), Ing. Capa. M. Giandotti (Parma), Gemes, Jose, Colonel L. Matteuzzi (Rome), Murguia, Prof. C. Negro (Turin), Prof. L. Palazzo (Rome), Prof. Gaetano Platania (Catania), Prof. Giovanni Platania (Catania), Prof. B. Paoloni (Montecassino), Petri, Prof. G. B. Rizzo (Messina), Prof. C. Somigliana (Turin), Prof. L. Taffara (Rome), Lieut. Mario Tenani (Vigna di Valle), Prof. F. Vercelli (Trieste), Conte Antonio Cittadelle Vigodazere (Turin).

Portugal.—Prof. Azevedo Gomes (Lisbon), Vice-Admiral Neuparth.

Spain.—Colonel Juan Cruz-Condé (Madrid).

Sweden.—Dr. Axel Wallén (Stockholm).

United States.—Dr. H. H. Kimball (Washington).

There was a tendency to regard the meeting as an ordinary assembly for reading and discussing papers regardless of the new feature of the disposable francs; but in the end a number of resolutions found their way into the Minutes and have provided the Bureau of the Section with sufficient occupation for the two years that elapse before the meeting in Madrid.

At the end of the meeting the Executive Committee of the Section was constituted as follows:

President.—Sir Napier Shaw.

Vice-Presidents.—Colonel Delcambre, Dr. Marvin.

Secretary.—Professor Eredia.

Other Members.—Professor Gamba, Dr. Simpson, Dr. Wallén.

Meteorologists are also interested in the proceedings of the sections for Terrestrial Magnetism and Electricity (President, Dr. C. Chree), Physical Oceanography (President, the late Prince of Monaco), Land Hydrography (President, B. H. Wade), and perhaps also Vulcanology. On account of the impossibility of being in two places at the same time I can only speak of a joint meeting with Terrestrial Magnetism at which the question of thunderstorms was discussed by Dr. Simpson, Dr. Bauer, Sir Arthur Schuster, Commandant Jaumotte, Dr. Chree, and Dr. Pacini. We also heard about penetrative radiation (Dr. Millikan) and the relation of sunspots and atmospheric electricity (Dr. Bauer).

The operative resolutions of the Meteorological Section were:

1-2. *The Upper Air.*

Ballons-Sondes.

(*a*) That the Meteorological Section places at the disposal of the Executive Committee of the Section a capital sum of 15,000 francs for the initiation of the exploration of the upper atmosphere by means of *ballons-sondes*, in regions either on land or on sea which are of special importance from the point of view of the general circulation of the atmosphere, and which at present have no effective meteorological organisation.

That the method of procedure be to lend instruments and apparatus to persons who, though not necessarily meteorologists, are able and willing to undertake the research, and who have the necessary facilities, either an aeroplane or a ship.

That the Bureau of the Section be instructed to make an appeal to aero-clubs and yacht-clubs to solicit their collaboration in the exploration of the upper air by aeroplane or by ship.

That the Bureau of the Section be entrusted with the necessary apparatus and with the funds required for its despatch to those interested.

That the Bureau be authorised to spend an additional sum of 15,000 francs for the same object in the course of the next three years.

That the Bureau, with a commission consisting of MM. Delcambre, Gamba, and Simpson, be asked to select the regions on land or sea where observations are especially desirable.

Pilot-Balloons.

The sum of 5000 francs is at the disposal of the Executive Committee for the extension of the study of the stratosphere by pilot-balloons in the regions of permanent high pressure, in the desert regions of large continents, and over the equator. It is thought that the best method of procedure is to lend the instruments and to provide the necessary material for persons who are able and willing to assist.

That the Bureau of the Section appeal to the Directors of astronomical and magnetic observatories for their assistance, especially in the matter of personnel.

That, if necessary, the Bureau have the power to requisition additional sums up to 30,000 francs for the same object during the three years which follow the present meeting.

3. *Convection.*

That the Bureau of the Section be instructed to invite the co-operation of *savants* of countries adhering to the Union on questions relating to the details of convection, either by experiments on the ascent of light or warm gas, by observations of convectional phenomena in clouds, or by the calculation of the process of ascension from the point of view of the influence of the friction of the environment.

4. *Radiation.*

That the Bureau of the Section be instructed to present a short report on the state of our knowledge of the radiation of the sun, of the sea, and of the air from the point of view of the general circulation of the atmosphere, which may give to the members of the Union information on the loss of heat and consequently on the potential temperature of the different layers of the atmosphere.

That the Section of Meteorology of the International Union take steps to convey to the Ministry of Public Instruction in Italy the wish that the Astronomical Observatory of Naples should be put into condition to continue and develop its researches which have an evident international interest.

The Section of Meteorology of the International Geodetic and Geophysical Union records its appreciation of the excellent work done by the Astrophysical Observatory of the Smithsonian Institution of Washington in determining with a high degree of accuracy the intensity of solar radiation outside the earth's atmosphere. It is of the opinion that the daily values now being obtained at Mt. Montezuma, Chile, and Mt. Haque Hala, New Mexico, will prove of great value in the solution of certain meteorological problems. It therefore expresses the hope that these determinations may be continued for a considerable period of years.

5. *Transparency and Dust.*

The Union of Geodesy and Geophysics allots to the Meteorological Section the sum of 2500 francs for the purchase of a certain number of specimens of the instrument described (jet-apparatus) and its gratuitous distribution to certain observatories selected for the purpose in order that the delegates of other nations adhering to the Union may make observations on this subject and communicate them to the Bureau of the Meteorological Section of the Union.

It has been established in France that certain kinds of clouds produce beneath them haze, sometimes very thick, which may reach to the ground.

On the same subject M. Gamba asks that a comparison be made of the instruments designed for the measurement of the transparency of the air in times of mist and fog.

6. *Hydrogen in the Atmosphere.*

That the Bureau of the Section be instructed to make inquiries as to the steps which are necessary to determine the amount of hydrogen in the atmosphere by analysis in different localities and at different heights, and to draw up, for the next General Assembly, a proposal on the methods of solving the question and their cost.

7. *Forecasting Weather.*

That the Bureau of the Section take steps to obtain from the several countries a reasoned statement of the methods which they employ in the general forecasting of weather.

8. *Forms of Cloud.*

That members of the Union who are interested in questions of the different kinds of clouds be asked to put themselves in communication with the Commission which has been constituted by the International Meteorological Committee for the study of the subject from the point of view of both pure and applied meteorology.

9. *Presentation of Data in Modern Statistical Form.*

The Section of Meteorology, having heard Prof. de Marchi's account and the suggestions put forward by M. Wallén, desires that the International Meteorological Committee should take into consideration the use of modern statistical methods for the calculation of normal values of the meteorological elements, and more especially of rain.

10. *Co-operation with the International Meteorological Organisation.*

In view of the International Conference of Directors of Meteorological and Magnetic Institutes which is to be held in Holland in 1923, this Section is of opinion that the Conference of Directors should be invited to consider whether there is any overlapping between its functions and those of the Union, and to make suggestions for the closest collaboration between the two organisations.

The occasional papers which were read before the Section included: Forecasting by Harmonic Analysis of Barographic Curves (Francesco Vercelli); The Service of Forecasting for Ships in Portugal, and the Use of Observations of Swell on the Portuguese Coast for the Weather Service of Morocco (Admiral Neuparth); The Formation of Hail (Professor Artom).

Such is the bare record of proceedings. Further particulars are given in the Procès-verbaux of the meeting issued from the press of the Lincei, 1922. Let me wander a little into a wider field of speculation.

Looking back across the vista of history, one may remark that among the characteristics of the high and mighty is the devotion of a good deal of time and energy to the art of killing each other, and, when not preoccupied in that way, the occupation of their leisure hours is killing something else: in either case success is estimated by the bag.

That kind of occupation ought not to be so attractive as finding out how nature manages to integrate her differential equations without hoisting the sign of impossibility or resorting to the Coptic alphabet. But it is a universal form of human enjoyment not altogether unknown to the scientific, reminding one perhaps a little of barbarous ancestry, but even in the twentieth century to be taken as we find it for better or worse.

At Rome we were, I am glad to say, much more concerned with the integrations of natural processes than with making an untimely end of any other form of activity. Perhaps it was that we all went so much in fear for our own lives either as pedestrians or voiturians in the narrow streets of the Eternal City that the appeal of the chase was less insistent than usual; we had a feeling that the most agile hunter might find himself in his turn on the run, with a bonnet or a mud-guard or a shaft within a few inches of his back.

And yet I think you will find that the mention of the International Union for Geodesy and Geophysics (Meteorological Section) is not altogether without a soupçon of the primeval instinct of humanity. The initial resolution of the Conference of London starts from that point. There have been in the air from time to time suggestions that now that the Academies have taken up the question of scientific research in real earnest the occupation of such creations of the Victorian Age as international assemblies of the directors of institutes and observatories, with no money to dispose of and no powers of coercion, will be gone. It will be noticed that in Rome we were content with asking the next assembly of Directors to review the question of overlapping and making other suggestions of like character.

My belief is that the Academic Union will find the Directors' Conferences an immense assistance in their arduous undertaking. Leaders of meteorological thought will, it is hoped, not be absent from either. The Conferences will only become unnecessary if instead of keeping its attention fixed on research in the rather lofty sense in which I defined it at the outset the Union should subside into the not less useful but much less exalted task of organising observations which are the common duty of the meteorological establishments of the world. That would indeed be the missing of a great opportunity. For a full generation within my own knowledge meteorologists have been reproached for compiling observations and still more observations. On one occasion the present Secretary of the Research Council himself suggested that the proper programme for meteorology was to suspend observations altogether for five years and devote all the time, energy, and money to discussing the observations. There is no short cut that way. Let me repeat. There are two sides to meteorology; one is the provision of material and the other the inductive and deductive elaboration of the science. The body of workers that provides the one is not, generally speaking, the same body as that which must do the other, if it is to be done at all. You won't help a single meteorologist in London by discouraging observations in Jan Mayen, Baffin's Bay, or the Sahara. The inauguration of the Meteorological Section of the Union opens up a way to removing the old-standing reproach. Let us hope that the academic potentates passing along it may abstain from the sport of exterminating the aborigines who have paved the track for the academic chariot. Let us aim at bringing new encouragement to those who, during their official lifetime, while dealing with the daily requirements of the nations for whom they work, have been striving towards the very objects which the academies have now in view, without the facilities for filling gaps and stimulating research which the Union is fortunate enough to have at its disposal.

Dr. G. C. SIMPSON at the conclusion of the paper said he knew that only the audience present would be able to realise how much of the success of the meeting in Rome was due to Sir Napier Shaw. If he had not been there the meteorological meetings would have fallen absolutely flat; he ran all the meetings and also was his own translator and made the whole thing go with a swing. He appeared to be the only President of the Bureaux who realised the importance of the francs that were going and he spent those at his disposal while the others remained in the bank. There was one thing—what was to be the relationship in the future between the new International Union and the Committee of Directors? He felt there was real advantage in having two organisations and there was no need for any overlapping. The business of the Meteorological Service of a country had become so big and so mixed up with the Government of the country that there was any amount of work for the Committee of Directors if they gave their whole attention to the meteorology of the public services. They need not be affected by this new Committee. There were on the whole few persons in this country outside the Meteorological Office and the Society who were interested in meteorology. There was not the wish to investigate meteorological and scientific problems for their own sakes, as, for instance, in the universities of Germany, where meteorological studies were taken as part of physics, and they had their researches in meteorology as in sound, light, or heat. There was nothing like that in this country. We had to stimulate meteorological interest here for its own sake and not as a way into a well-paid Government department, and this was what the speaker felt about the duties of the two organisations. One more point was that the Society ought to see that they had an *ex officio* member of the National Committee of the Geodetic and Geophysical Union, which is elected by the Royal Society. The Society ran side by side with the Meteorological Office in representing meteorology in this country and he wished it would make sure that the scientific side was kept in view by the whole country.

The PRESIDENT (Dr. C. CHREE) after referring to a few incidents of the meeting at Rome, said he was sure they were much indebted to Sir Napier Shaw for the very lucid statement he had given.

Wind above the Night-Calm at Benson at 7 a.m.—*Long.* 1° 6′ *W.*, *Lat.* 51° 37′ *N.*

As is well known, the air in the first few hundred metres above the surface is frequently cooled by radiation at night in such a way that it becomes too stable for eddies to persist in it; and then it stagnates, while the general wind goes on above all night. In the morning the wind often does not descend to the anemometer until several hours after sunrise.

From observations made at 7 h., by shooting spheres upward, the occasions have been selected on which there was a rather sudden increase of wind speed between 0 and 300 metres, with nearly stagnant air below. The results are collected in the adjoining table. The occasion on which the discontinuity was sharpest was 1919, Nov. 27 d. 7 h., and it has been discussed in detail in a theoretical memoir to be read at the Royal Society, 1923, Feb. 8.

Date.	Horizontal range of visibility in km.	Height of top of calm above ground.	Greatest observed speed of wind above.		Geostrophic wind.		Height of greatest observed speed above ground.
			Azimuths from N via E.				
		metres	from	m/s	from	m/s	metres
1919 Oct. 22	0·5	120	180°	12	185°	7	170 See Footnote
The wind reached the anemometer at 10 h. 55 m. G.M.T.							
Nov. 1	4	100	13°	12	45°	11·5	230?
Nov. 27	1·0	200	68°	15	68°	6	230
Dec. 17	7	120	217°	13	248°	9	...
The speed at 50 m. was 4 m/s from SSW. It sank to a minimum of 2 m/s at 120 m., and increased rapidly above.							
1920 Feb. 25	0·5	150	135°	9	135°	3·5	230
Mar. 9	20	150	22°	9	338°	5	210
Balloon 40 minutes later showed a maximum speed of 9·6 m/s from 320° at 190 m.							
Mean speeds				11·7		7·0	

Footnote.—An incorrect reduction of this observation appears in *Weather Prediction by Numerical Process* (Cambridge Univ. Press), p. 85. It was made by a thick-layer formula which is unsuitable when the changes are so rapid.

The transition from the calm to the wind above was sometimes gradual. In these cases "the height of the top of the calm" is taken as the level at which $\partial^2 v/\partial h^2$ appeared to be a maximum, v being the resultant speed and h the height.

It is remarkable that the observed wind speed is on the average 1·7 times the geostrophic. Attempts to explain away the excess of this ratio above unity as an error of the projectile-method led to a re-examination of the constants of the spheres and to a study of the theory at the vertex, as set forth elsewhere, but they have not removed the discrepancy. So we must conclude that it is real, especially as on 1920, Mar. 9, the high speed was confirmed by a balloon observation. On Feb. 25 and Mar. 9 there was some evidence of a falling off of speed above the rapidly moving layer.

The stability of the calm[1] may perhaps have some connection with the fact that Benson lies on a plain with hills rising to about 150 metres above it in two long lines, the Chilterns with the Berkshire hills on one side, the Cotswolds on the other.

These observations were made in the course of official duties, and are communicated by permission of the Director of the Meteorological Office.

LEWIS F. RICHARDSON.

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[1] See Georgii, *Ann. Hydrogr., Berlin*, **48**, 1920, pp. 207 to 222 and 241 to 261.

THE STUDY OF RADIOTELEGRAPHIC ATMOSPHERICS IN RELATION TO METEOROLOGY.

By C. J. P. CAVE, M.A., and R. A. WATSON WATT, B.Sc., F.Inst.P.

[Received October 17—Read December 20, 1922.]

THE naturally occurring electromagnetic waves of frequency below 300,000,000 per second, which are known to the radiotelegraphist as atmospherics, strays, X's, sturbs, and statics—now officially as atmospherics only—are clearly a legitimate object of study by the meteorologist or, more generally, by the geophysicist, and it seems desirable to set down in a collected form the chronology of such studies as have been attempted, in so far as they relate to the more generally recognised aspects of meteorology.

The atmospherics manifest themselves in all radiotelegraphic receivers as disturbing noises of varying character; they have been classified by the British Association Committee for Radiotelegraphic Investigations into three main groups, viz. Clicks, "sharp isolated knocks"; Grinders, "a more or less prolonged rattling or grinding noise"; and Sizzle, "a buzzing or frying noise, often heard during a white squall."

Historically, the meteorological study of atmospherics preceded the introduction of practical wireless telegraphy.

Popoff, of Cronstadt, in 1895, studied the incidence of lightning flashes by using a long vertical conductor and a coherer with an automatic decohering mechanism such as was used later in radiotelegraphy.

Boggio Lera, in Italy, developed a more sensitive arrangement in 1898, and recorded strong and feeble disturbances separately. He showed that every lightning flash visible at the recording station operated his recorder, and, a more important contribution, that the approach of electrical storms was indicated by the apparatus several hours in advance of the arrival of the more familiar meteorological symptoms.

Tommasina, using a novel form of coherer, confirmed these results in 1900.

Fenyi, in Hungary, showed in 1901 that his recorder kept an effective watch on thunderstorms within 100 km.

Turpain, of Poitiers, about 1903, developed apparatus of considerable elaboration for recording disturbances more or less quantitatively, and made a series of observations establishing the value of radiotelegraphic observations of atmospherics in the forecasting of thunderstorm conditions.

Jegou, Flajolet, Delval, and Duroquier, in France, all contributed to the study of the meteorological relations of atmospherics in the pre-war era.

Mosler, in Germany, made a series of observations from August 1911 to July 1912, and found that atmospherics increased in number as grey storm clouds approached the station, and decreased as the clouds receded. He also found that great atmospheric disturbance accompanied a high atmospheric potential gradient, especially when this was rapidly varying. In his experience atmospherics were relatively slight under a uniform cloud sheet, in rain, and in fog. A result contrary to the experience of many other observers, earlier and later, is his conclusion that lightning discharges more than 100 to 200 km. distant do not affect the receiver.

It is curious to note that Mosler may have missed observing the directional travel of atmospherics by a simple mischance. He listened in on a North-South and on an East-West aerial, and finding no marked difference in the amount of atmospheric disturbance, rejected the idea of a sharply marked direction of propagation. But if we assume that the mean direction of arrival of atmospherics in Germany is not very different from that for Britain, a probable interpretation of this result is that both his aerials were nearly equally inclined to the direction of arrival; had circumstances compelled him to use a N.E.-S.W. and a N.W.-S.E. pair of aerials, the result might have been different.

Crawley, observing in the Mediterranean, found that severe atmospherics accompanied low barometer, high temperature, and low humidity. The sirocco, despite its high humidity, was also accompanied by atmospherics.

In Britain, the British Association Committee for Radiotelegraphic Investigations had begun to organise observations on an adequate scale when their operations were interrupted by the outbreak of war in 1914. The report of the Committee in the Report of the British Association for 1915 contains a summary of the results established by the observations made under their scheme. The principal result is that "X storms," periods of exceptionally severe atmospherics, are periods of low barometer, high wind velocity, rapid change of temperature, heavy rainfall, and, especially, of rapid fluctuations of pressure. The observations also showed that atmospherics from lightning flashes were not usually heard simultaneously by two stations more than 100 miles apart.

In 1912 one of us (C. J. P. C.) returning from Budapest brought back a coherer lightning recorder of a modified Fenyi pattern. This was brought into use at the Branch Meteorological Office, South Farnborough, in 1915, with a view to the issue of warnings to aircraft when line squalls and thunderstorm phenomena were anticipated.

Its use showed that, with care in maintenance and observation, valuable warnings could be issued, but the experience of stations to which similar instruments were, later, issued was that maintenance was excessively troublesome.

At this stage Dr. R. Whiddington (now of Leeds University) suggested that the recorder at Farnborough should be supplemented by a radiogoniometer to determine the direction of arrival of atmospherics, with a view to the location of thunderstorms by simultaneous observations. This opened up the prospect of a new and valuable method of investigation, and here again it seems desirable to record previous suggestions of similar import.

The first reference known to the writers, to the application of a directive antenna in the study of atmospherics, is contained in Senatore Marconi's paper read before the Royal Society in 1906. He reports having observed that atmospherics appeared "to proceed from certain definite directions which vary from time to time," and suggests that "it would be exceedingly interesting to investigate whether there exists any relation between the direction of origin of these waves and the bearing or direction of distant terrestrial or celestial storms, from whence these stray electric waves most probably originate." Marconi proposed to carry out some further investigations on the subject, but no corresponding publication is known to us.

It is to be noted that the observations in question were made with the incompletely directional bent antenna, not with the radiogoniometer which was patented by Bellini and Tosi in the year 1907. The Marconi bent antenna gives a polar curve of reception which is of the form $a + b \cos \theta$, where the ratio of a to b is not readily determinable and, as a result, the bent antenna as a receiver is quite unsuitable for direction.finding of any but the roughest type. The radiogoniometer, with its pure cosine curve, is, on the other hand, an instrument of considerable precision.

In 1911 Dr. J. Erskine Murray, in detailing thunderstorm experiences which led him to suppose that thunderstorm phenomena might sufficiently account for all atmospherics, stated that he proposed to make observations with a direction finder. He did not, however, put the proposal in practice, and we therefore conclude that the first completely directional observations on atmospherics were those made at Aldershot on Dr. Whiddington's suggestion, in June 1915, as detailed in this paper.

It is of interest to note that the priority thus established for the observations at M.O. Radio Station, Aldershot (as the radiotelegraphic sub-establishment of the Farnborough Office came to be called), is one of a few months only, for directional observations on atmospherics, though not for meteorological purposes, were made at the Marconi station at Belmar, New Jersey, in and after September 1915. A few observations were also made in Russia in October 1916 by the Marconi Company.

Work was begun with a Bellini-Tosi radiogoniometer, kindly lent by Dr. Whiddington, and an R.A.F. tuner Mk.1, with a crystal detector. The directional aerials were triangular, with a height of 65 feet and a base of 200 feet length, some 3 feet above ground. The aerials were oriented N.-S. and E.-W., and tuned to 600 metres.

The method of observation was to count the number of atmospherics heard per unit time with the goniometer set for maximum receptivity, first at North, then at N. 30° E., N. 60° E., etc. The approximate direction of minimum disturbance thus found was more closely explored at settings of 10° azimuth, and finally, when possible, located to 5°. The direction of maximum disturbance was then at right angles to the direction thus determined.

This direction has an ambiguity of 180°, the goniometer failing to discriminate the sense of the vector which it locates.

Observations are made on the minimum direction rather than on the maximum, because the former is much more clearly marked than the latter, the polar curve of intensity being of cosine form.

The sensitivity of the apparatus used, if judged by present standards, was extremely low, yet it was sufficient to establish the validity of the assumptions underlying the proposed method of location.

General observations on atmospherics at once indicated the principal limiting factor affecting the sensitivity of the apparatus in use. A new goniometer was constructed to work on a wave length of 5000 metres, and the antennae were improved by increasing the base length to 280 feet and raising the base to 10 feet above ground level. The new arrangements were successful in detecting a storm of December 1, 1915, the circumstances of which may be described from a report dated December 22, 1915.

> On December 1 there were thunderstorms along the South coast of England from the neighbourhood of Scilly (0 h. 15 m. to 3 h. 30 m.) to Dungeness (14 h. 30 m.).
>
> There was probably more than one storm. In Sussex there were certainly two. At Selsey there was distant thunder at 9 h., at Worthing a thunderstorm at 11 h. 30 m., and at Tunbridge Wells one at 12 h. 30 m. What appears to have been a second storm reached Rowlands Castle at 10 h. 15 m., Westbourne at 11 h. 30 m., and Selsey from 11 h. 30 m. to 12 h. 30 m. Later in the day there was another storm which was just south of Jersey at 18 h. The lightning seen from several stations in this country was probably due to this storm moving up Channel or along the French coast.
>
> The automatic recorder at Farnborough began to record lightning just after 9 h., with the exception of a few isolated records during the night. It continued recording with intervals into the afternoon.
>
> The direction finder gave a direction of a storm on the North-South line through Farnborough between 12 h. and 12 h. 30 m. This corresponded with the storm at Selsey, which is due south of Farnborough. After about 12 h. 35 m. there were very few loud sounds in the direction finder; this corresponds with the fact that the storm ceased to produce electrical discharges at this time, for when it reached Worthing at 12 h. 30 m. there was a violent squall with hail, but no thunder is reported at this time. In all 46 loud sounds were heard in 42 minutes and the minimum at 270 was very well marked.

Further experience showed that an extension of the method was justifiable, and the assistance of the Admiralty was invoked. Commencing in March 1916, the coastal Direction Finding Stations communicated to Farnborough the intensity and apparent bearing of atmospherics at frequent intervals during the day. Some twelve stations were involved in this reporting scheme, and in the four years, 1916–20, over 15,000 observations of apparent direction of arrival of atmospherics were reported. The exigencies of service work under war conditions made it impossible for a rigid programme to be adhered to, consequently many cases arose in which only one station was able to observe at one time. In the two years 1916–18, however, there were approximately a thousand cases in which three or more stations obtained bearings within the same hour, and in half these cases an intersection was obtained. It is not proposed to detail here the analysis made by one of us (R. A. W. W.) of the results of these observations; it is hoped to publish this at an early date.

Some of the more outstanding successes may, however, be cited here.

The first thunderstorm to be recognised as having been located by the intersection of bearings from three Direction Finding Stations occurred in the south of Ireland on July 24, 1916, at 20 h. G.M.T. The bearings indicated a centre of disturbance at the source of the Suir and the Nore, and subsequent meteorological reports showed that exceptionally heavy thunderstorms were experienced in the region during the afternoon and evening in question. This storm was 280 miles from the most distant observing station.

A thunderstorm originating 250 miles west of Bordeaux at 6 h. on August 9, 1916, was tracked to a position near Rochefort at 15 h., and 130 miles west of Lyons at 20 h., while next morning at 6 h. there were still indications of a storm 90 miles north-east of Biarritz.

Meteorological records showed thunderstorms at Rochefort at 14 h., at Bordeaux during the day, at Biarritz at 18 h., at Toulouse during the night, at Perpignan at 2 h. on the 10th, at Lyons at 14 h. on the 10th.

On August 12, 1916, at 19 h., the intersection of three bearings at a point a few miles west of Whitby corresponded to a thunderstorm which reached Whitby at 19 h. 40 m.

On August 19, 1916, at 20 h., three stations indicated a disturbance 50 miles south-west of Holyhead. A later Meteorological Office message from Holyhead reported "20 h. 30 m., lightning in S.W."

The correct bearing of a storm at Venice at 7 h. G.M.T. on October 16, 1916, was reported by stations at Roscarbery and Lizard. The distance from Roscarbery to Venice is over 1000 miles.

The directions of storms at Spurn Head and Prawle Point in early 1917 were obtained at the M.O. Radio Station with an accuracy within one degree. A thunderstorm in West London at 13 h. 30 m. on June 18, 1918 was observed at the M.O. Radio Station with an accuracy of bearing which distinguished between West and East London.

On June 28, 1917, at 18 h., an intersection near Amiens was obtained. The Meteorological Field Service at G.H.Q. were able to confirm the occurrence of this thunderstorm.

On October 11, 1917, a thunderstorm occurred at Jersey at 7 h. The radiotelegraphic observations gave an intersection between Jersey and S. Malo at 4 h. 30 m.

On September 5, 1918, at 13 h., thunder was heard in the S.S.E. from Aldershot, the direction of arrival of atmospherics was 150°; half an hour later the thunder was E. to S.E., the direction of arrival 135°; at 14 h. the corresponding bearings were N.N.W. and 345°.

These typical cases serve to show that the method of thunderstorm location by radio direction finding was an established one as early as the middle of 1916, and that it has been tested over a range from 5 to 1000 miles.

Directional observations on atmospherics, on a more restricted scale, were taken up in America and France in 1917, but the writers are not aware of any attempt to bring a network of stations into the observing system; the French and American work appears to have been limited to observations with a single direction finder, from which, of course, definite locations (as apart from bearings) cannot be obtained.

Acknowledgments are due to many who helped the development of the research on thunderstorm location. Dr. R. Whiddington, who made the suggestion on which the work was begun, gave frequent and invaluable aid; Sir Napier Shaw, as Director of the Meteorological Office, lent a generous sympathy to this new line of work at a time when the ratio of work to staff in the Office was exceptionally high; the Admiralty, through Captain Slee, R.N., made the large scale tests practicable; and the staffs of the stations concerned performed miracles of direction finding on isolated atmospherics as a "side show" in their very arduous war signal service.

DISCUSSION.

Commander J. A. Slee, referring to the help rendered by the Admiralty, said that during the War it had not been possible to do very much because the stations which could be made use of for observing the direction of atmospherics were all fully occupied on the service for which they were designed. In their construction everything that was possible had been done to reduce interference with their proper duties caused by atmospherics, and they found themselves in the position of being called upon to observe disturbances which they were in the habit of doing their utmost to minimise. The best that could be done was to appoint certain hours of the day when for a few minutes atmospheric disturbances could be observed. He had not hitherto heard that much success had attended these efforts, but was very glad to hear of it now.

There were one or two points which he felt should be brought to the attention of the Society. For one thing, wireless direction finders nowadays are able to distinguish the sense as well as the azimuth, and there is no longer any confusion as to the real direction. Secondly, the business of observing the direction of atmospheric disturbances is always rather difficult. In all systems of direction finding any accurate determination of the direction is ultimately made by observing the direction in which the sound concerned is inaudible, and to make this determination, a short space of time, amounting to two or three seconds, is required even by the most expert. The duration of the sound produced by an ordinary single atmospheric seldom lasted as long as a quarter of a second, and as a direction finder indicates that there are generally several such disturbances going on at once in different directions, it is extraordinarily difficult to obtain any accurate observation of any particular atmospheric disturbance. All that is possible is to obtain a broad idea as to the direction in which atmospherics are most or least prevalent. It is only on very rare occasions that a really accurate bearing expressed in degrees can be obtained.

A very great deal of work has been done with a view to ascertaining the most general places of origin of atmospherics with the object of being able to avoid such places when considering the position of new wireless receiving stations, and also with a view to avoiding operating along the direction of such sources of origin. Information to hand is not sufficient to say whether such sources of atmospheric disturbances are actually the positions of fully developed thunderstorms.

In many places of the world the observable strength and direction of atmospherics is to some extent periodic, both direction and intensity varying from hour to hour during the day and also varying at different seasons of the year, the variations recurring with fair regularity, but so far it is not known whether such disturbances are originally caused by actual thunderstorms.

It is clear then that the difficulty of making accurate observations of the direction of atmospherics is very great, and that at present we do not appear to have sufficient evidence to enable us to associate all atmospherics, whose direction may be observed, with the presence of thunderstorms.

Captain Sir David Wilson-Barker, after congratulating the authors, suggested that on board ship, in compiling the meteorological logs, reports of atmospherics should be given by the wireless operators.

Sir Napier Shaw said that his name had been mentioned in connection with the original starting of the inquiry. As a matter of fact it was Mr. Cave who brought a recorder from Hungary and initiated the investigation, but he had always been interested. This paper was probably the introduction to other papers giving details of the results and conclusions. He understood that the rain of an advancing depression had been identified as giving rise to atmospherics: the locality of the rain is particularly defined as being in the front of advancing depressions. Whenever he had urged the application of this branch of physics to meteorology he had been warned off by the experts who maintained that in this case one ought not to expect the electrical disturbances to travel straight. The apparent direction was only that of the last refraction. If the atmospherics arrived from the south-east they did not necessarily originate there; the path they would take from their origin to the instrument which recorded them was not a straight line. A SE wind as recorded on an anemometer furnished an analogous case. He was, however, glad to see that in the illustrations which had been given, as in others which he knew existed, there had been cases in which direct lines from two stations converged upon localities in which thunderstorms actually occurred. It was then difficult to resist the conclusion that the thunderstorm has something to do with it. Mr. Watson Watt might have said what steps had been taken to continue the inquiry. The inquiry was still going on, and Mr. Cave was still participating in the work. It seemed probable that regular observations of atmospherics would be of great assistance to meteorology. Finally, he wished to emphasize the importance of Commander Slee's assistance at a difficult time.

Dr. G. C. Simpson referred to the question raised by Sir Napier Shaw as to whether this work was meteorological, and he agreed that meteorology and wireless could learn a great deal from one another. There are several distinct effects or influences of the atmosphere on wireless telegraphy, and if the atmosphere acts on anything which can be measured, by making those measurements we were bound to learn something about the atmosphere. Mr. Watson Watt had made reference to thunderstorms as causes of atmospherics, but we must go a little beyond that. There appear to be three ways in which the atmosphere affects wireless. The first is with regard to atmospherics. Then, secondly, there is a peculiar effect of the atmosphere on the transmissibility of wireless waves. Signals from America varied in audibility from time to time, and are at their worst when the twilight band is between England and America. The third effect is connected with wireless direction finding, for if you measure the direction from which a signal appeared to come from a certain station the apparent direction varies very widely. Each of these obviously depended on the atmosphere, because there is a marked daily variation in each: (1) Atmospherics are pretty bad during the day, then just before sunset they go to a minimum, and immediately after sunset they become large and extend throughout the night. (2) When the twilight band is between England and America you cannot signal between them. (3) During the daytime you can get the direction of transmission to almost 1° or 2°, a variation of 3° is exceptional, but at night your error may be something like 50°, quite a different order of magnitude. When we investigate these cases we cannot help but get some information about the atmosphere, not only in the lower regions but also in the upper regions. He could not go into this, but would like to refer to the origin of atmospherics. Mr. Watson Watt had drawn attention to their association with thunderstorms. There was no doubt that a large discharge of electricity is bound to set up a wireless wave, but Mr. Watson Watt had found some connection with rain quite independently of thunderstorms. Much of his own work had been on the electricity of rain, but he could not see how the connection between rain and the radio wave was obtained. He was grateful to Mr. Watson Watt for bringing this subject before the Society. Since Mr. Watson Watt had left the Office he had got into a wider sphere and was better able to prosecute his researches.

Mr. L. F. Richardson asked Mr. Watson Watt if he could explain the origin of the peculiar atmospherics which were experienced at Eskdalemuir on the telephone, which was connected with an overhead wire in a lonely valley. In addition to the ordinary clicks there was a "swishing" sound. The frequency of the vibration diminished as the swish went on. This property was characteristic of the sound of a shell passing high overhead. Mr. Richardson had the idea, perhaps a mad one, that the swish might be produced by a meteorite.

Mr. C. J. P. CAVE said he would like to add his thanks to Sir Napier Shaw and to Commander Slee for what they had done in the early days to make the investigation possible.

Mr. R. A. WATSON WATT, replying to Commander Slee's remarks, said that we should be grateful to Commander Slee if he could follow up the studies which he had described, as the possible local origin of atmospherics ought to be carefully investigated. The present paper was carefully limited in scope; a discussion of the wider investigation which had developed from these beginnings would occupy too much of the Society's time. In answer to Mr. Richardson he said that a swishing sound similar to that described was characteristic of many atmospherics received without rectification.

It may be noted that strong atmospherics, of unspecified type, were reported as preceding the fall of a meteor off Halifax, N.S. The adoption of Sir David Wilson-Barker's suggestion would give valuable data for the plotting of world isopleths for atmospherics.

The deviations mentioned by Sir Napier Shaw are of great importance, but experimental evidence indicates that the highly damped wave trains constituting atmospherics are little subject to such deviations. There are, moreover, recognizable times and areas of bad deviation, in which data would be treated as suspect.

The results of the present investigation justify the assumption that such deviations would not lead to erroneous locations, though they might reduce the number of locations obtained. It is difficult to conceive that the bearings taken by three or more well located and widely separated stations could be vitiated by deviations of such very special magnitudes as to convert the intersection corresponding to a true source into a good intersection at a sensible distance from that source. The checking of the intersections actually obtained, against reports of thunderstorm and convective phenomena, is producing a very strong mass of evidence for the correspondence between the points of intersection (without correction for any form of deviation) and loci of strong convection. Some data on this point will be found in a recent note on "The Origin of Atmospherics" (*Nature*, **110**, 1922, pp. 680–681).

WINTER THUNDERSTORMS IN THE BRITISH ISLANDS.

By C. J. P. CAVE, M.A., J.P.

[Received November 11—Read December 20, 1922.]

AN inquiry into the occurrence of thunderstorms in the first three months of the year was made in 1916, 1917, 1918, and 1920. The method of inquiry consisted in sending circulars to the observers who send returns of rainfall to the British Rainfall Organization asking them to send a report of any thunder or lightning observed; a letter was also sent to *Nature* asking for similar information, and reports were noted in the *Daily Weather Report* of the Meteorological Office.

Out of the 5000 observers comparatively few sent in records, but some of the observers were very assiduous and sent in reports with great regularity whenever thunderstorms occurred in their neighbourhood. This was particularly the case with a few observers in the north of Ireland and on the west coast of Scotland, whose observations were of great value.

Table I. gives the number of days on which storms were reported from the British Islands as a whole, and from England, Scotland, and Ireland respectively. The number of days is very remarkable; out of the 362 days in the four years there were storms somewhere in the British Islands on 147 days, that is on nearly 41 per cent of the days. The smaller number of days recorded from Scotland and Ireland is almost certainly due to the smaller number of observers in these districts

TABLE I.—NUMBER OF DAYS ON WHICH STORMS WERE REPORTED (THUNDER ONLY, LIGHTNING ONLY, OR BOTH THUNDER AND LIGHTNING).

MONTH.	1916.	1917.	1918.	1920.	Total.	England and Wales.	Scotland.	Ireland.
January	23	10	6	19	58	35	35	22
February	24	3	11	8	46	26	28	25
March	17	11	3	12	43	37	7	18
Total	64	24	20	39	147	98	70	65

TABLE II.—NUMBER OF DAYS ON WHICH LIGHTNING ONLY WAS REPORTED. (INCLUDED IN TABLE I.)

MONTH.	1916.	1917.	1918.	1920.	Total.
January	9	2	4	2	17
February . . .	5	1	1	5	12
March	3	1	...	1	5
Total	17	4	5	8	34

compared with those in England. Table III. gives the number of reports sent in. These figures do not indicate the number of observers, as one observer might send in more than one report, but they indicate roughly the proportions in the different parts of the British Islands. As a matter of fact Scotland and Ireland are not so well represented as appears from these figures, for, as has already been mentioned, some of the observers both in Scotland and Ireland sent in a number of reports each.

TABLE III.—NUMBER OF REPORTS.

	1916.	1917.	1918.	1920.	Total.
England	186	47	63	243	539
Scotland	71	9	16	51	147
Ireland	119	12	23	67	221
Total	376	68	102	361	907

TABLE IV.—DAYS ON WHICH STORMS WERE REPORTED AND NUMBER OF REPORTS RECEIVED.

DATE.	JANUARY.				FEBRUARY.				MARCH.			
	1916.	1917.	1918.	1920.	1916.	1917.	1918.	1920.	1916.	1917.	1918.	1920.
1	115	...	...	2	...	...	...	1	8	...	...	...
2	27	2	...	...	...	...	...	...	2	...	...	...
3	3	...	1	...	2	...	...	...	4	...	...	...
4	8	1	...	...	22	...	1	...	...	...	...	...
5	3	1	...	...	4	1	1	...	...	...	...	...
6	2	1	...	...	47	...	...	...	2	...	...	...
7	3	1	...	4	30	...	4	1	...	...	...	7
8	1	6	1	12	64	...	15	2	1	...	...	2
9	...	3	...	3	13	...	53	...	9	...	...	...
10	1	...	...	7	3	...	2	2	1	...	...	...
11	1	...	...	158	2	...	4	...	...	7	...	...
12	1	...	2	1	3	...	...	...	3	1	...	3
13	...	3	...	17	5	1	...	...	24	...	...	4
14	...	7	1	3	36	...	...	...	12	...	1	...
15	...	...	1	2	6	...	...	2	2	...	...	...
16	...	1	...	...	63	...	...	...	...	...	...	...
17	...	...	...	...	34	...	...	...	...	...	...	1
18	3	...	2	...	1	...	...	1	...	...	...	...
19	29	...	...	9	...	...	...	1	2	2	...	...
20	159	...	...	1	...	2	1	...	...	1	...	...
21	1	...	...	...	1	...	...	...	...	2	...	...
22	5	...	1	...	3	...	1	...	...	1	...	...
23	2	...	...	...	1	...	...	1	...	...	...	...
24	1	...	...	2	3	...	...	...	6	...	...	...
25	3	...	...	1	1	...	...	...	14	1	...	2
26	3	...	...	1	...	...	1	...	18	...	...	8
27	1	...	...	16	1	...	1	...	5	...	...	2
28	...	...	...	6	1	...	...	...	1	2	...	14
29	3	...	...	4	1			...	...	7	3	12
30	1	...	...	...					...	12	...	25
31	...	...	...	14					...	2	5	7

The majority of the storms were, as would be expected, of the line squall type, sharp storms lasting only a short time at any one place. Very often their travel across the country can be traced, and in some cases isochronous lines can be drawn.

SUMMARY OF THE MOST NOTICEABLE STORMS OF THE LINE SQUALL TYPE.

1915. *Dec. 30th and 31st.*—These days though not included in the summary were very disturbed. Depression off the west of Ireland; steep temperature gradient between S.W. England, 50° F., and southern Scandinavian coast, 20° F.; instability seems to have been caused by warm Southerly wind rising over cold Easterly wind from continent.

1916. *Jan. 1st.*—Probably several storms following each other; first report from Westport, Co. Mayo, at 4 h., last from Barton on Humber at 14.20. Veer of wind and drop of temperature noted. The Southerly wind had spread as far as Scandinavia, but there was a strong temperature gradient between the west and east of England. A "V" depression crossed the country.

Jan. 19th.—Storms in west of Scotland, north of Ireland, and Cheshire. Commencement of succession of storms of following day.

Jan. 20th.—West of Scotland and various parts of Ireland in early morning; southern and south midland counties of England between 6 h. and 11.30. Typical line squall in south of England travelling at about 40 miles per hour. The front of the storm stretched from Bude to Hereford, and perhaps as far as Shrewsbury at 8 h., from south Devon to Uttoxeter at 9 h.; it had narrowed down to a length of 25 to 30 miles in Berkshire and Oxfordshire at 10 h., after which the thundery character of the disturbance ceased, but there was thunder and lightning at Eastbourne and Seaford at 11.15. There was cold air, 40 to 41° F. in the west of Ireland, and warm, 49 to 50° F. at the mouth of the Channel, and an irregularity of pressure over the Irish Sea at 7 h. By the following day the temperature in the west of Ireland had risen to 50-53° F.

Feb. 3rd to 18th.—During these sixteen days there were thunderstorms somewhere in the British Isles on every day. An examination of the temperatures on various days indicates some steep temperature gradients, and there were strong winds from some westerly point most of the time. It would seem that in general the conditions favourable for storms are masses of air at different temperatures in close proximity, and a high wind velocity; it is easy to understand how, in these conditions, cold air may undercut warm air, or warm air may rise over colder air, with resulting instability. Maps have been prepared for Feb. 6th and 16th showing the change of temperature between 7 h. and 18 h. In both cases cold air is seen to have invaded regions which had previously been occupied by warmer air.

Feb. 6th.—Scotland west and south, Ireland west and north, South Wales, Lincolnshire. A map (Fig. 1) showing the change of temperature between 7 h. and 18 h. indicates a large drop of temperature during the day; cold air had evidently invaded the regions where the storm was mo pronounced. (Compare Feb. 16th, 1916.)

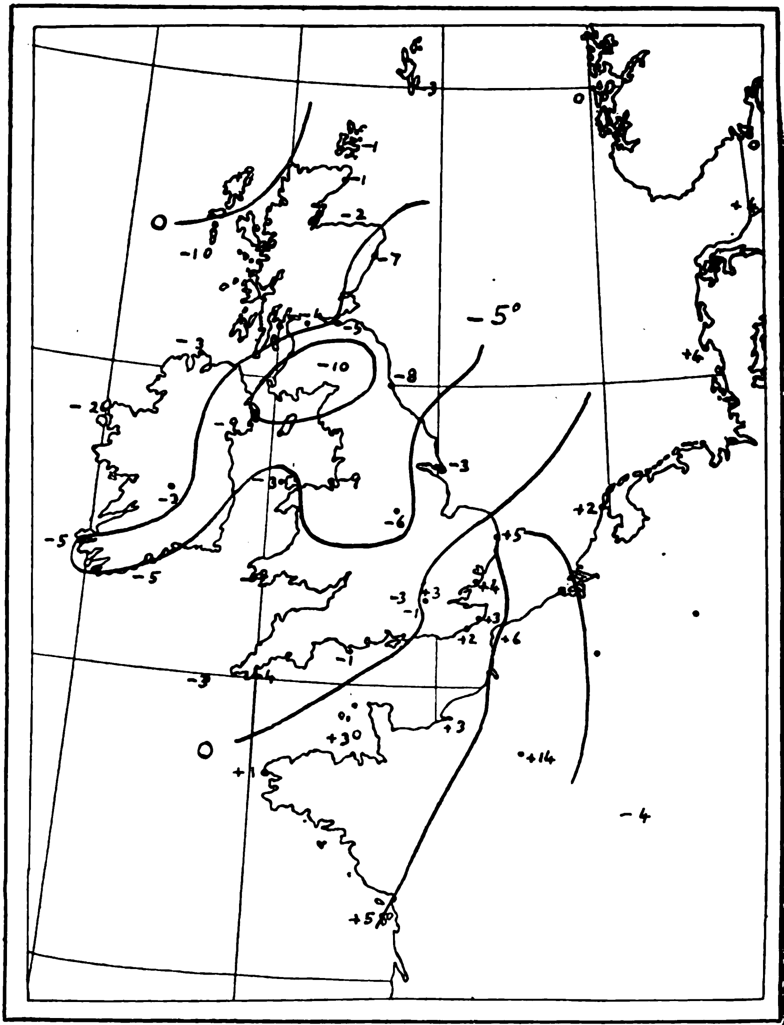

FIG. 1.—Change of Temperature between 7 h. and 18 h., Feb. 6, 1916.

Feb. 8th.—Stornoway, Co. Donegal, Co. Clare, Gloucestershi Devonshire, Somerset, Lake District, Wales. This day noticed because there seems to be no indication of any ste temperature gradient, though there were low temperatur 35 to 39° F., in the west of Ireland.

Feb. 11*th.*—A "V"-shaped depression with its axis from the Pentland Firth to Jersey is shown on the 7 h. map. Thunder was reported from Surrey in the early morning, and it is noticeable that there was a very steep temperature gradient over the south of England, Portland Bill 48° F., Benson 39°, Dover 38°.

Feb. 14*th.*—West and south of Scotland, west of Ireland, Cheshire, Yorkshire, Lancashire, Derbyshire, Leicestershire; various times, in England mostly from 10 h. to 11 h. Snow and sleet reported from as far west as Co. Clare. Very large temperature differences between north and south: Valencia 44° F., Blacksod 33°, Holyhead 46°, Tynemouth 38°.

Feb. 16*th.*—West of Scotland, west of Ireland, Cheshire, Yorkshire, Lancashire, Derbyshire, Staffordshire, Nottinghamshire, mostly between 15 h. and 18 h. Apparently a line squall in Lancashire, Derbyshire, etc.; first observation in this area Liverpool, 15.15, latest Hodsock, 17.15; rate of travel about 20 miles per hour; hail, sleet, and snow reported from many stations, including snow in Co. Donegal. Maps of the temperatures at 7 h. and 18 h. on this day (Fig. 2) show that cold air had moved down over the country from the north or north-west; in the south of England the drop in temperature amounted to over 10° F.

1918. *Feb.* 9*th.*—There were thunderstorms every day from the 7th to the 11th; but the storms on the 9th were the most numerous. There seems to have been a line squall which was particularly violent over the midlands. A rise of the barometer, a fall of temperature, and a veer of the wind were reported. There seem to have been several storms following each other, so that it is not possible to draw isochronous lines for any particular storm; most of the reports refer to the period from 19 h. to 21 h. The temperature maps for 7 h. and 18 h. on the 9th, and for 7 h. on the 10th, do not show any fall of temperature, but the 7 h. map for the 9th shows a wedge of cold air extending from the Orkneys to the centre of Ireland which was probably associated with the storm; there was certainly a fall of temperature during the passage of the storm, for it was reported from several stations, but apparently the temperature rose again later so that the maps do not show any fall.

1920. *Jan.* 11*th.*—This was the most disturbed day of the series from January 7th to 15th, on every day of which period there was a thunderstorm in the British Isles. Reports came from Ireland, all districts except the north-east, a few from Wales and Scotland, but most from England, Yorkshire, Lancashire, Derbyshire, Nottinghamshire, Lincolnshire, Norfolk, Suffolk, Essex, Hertfordshire, Oxfordshire, Buckinghamshire, Gloucestershire, Worcestershire. There was a definite line squall which crossed Wales, the midlands, the home counties north of London, and the eastern counties; most of the Irish reports refer to a later storm, but two or three seem to refer to this storm; the storm seems to have moved rapidly, 50 to 60 miles per hour in places. There was a very strong wind and heavy rain, hail, or sleet. A few stations reported a veer of wind and drop of temperature. In Yorkshire, etc., the storms occurred later and indicate that another storm, or succession of storms, passed over this part of the country. The 18 h. map shows a wedge of low temperature over Scotland and the Irish Sea which was probably associated with the later storms, and an area of low temperature over Lincolnshire with which the earlier storm may be associated (Fig. 3).

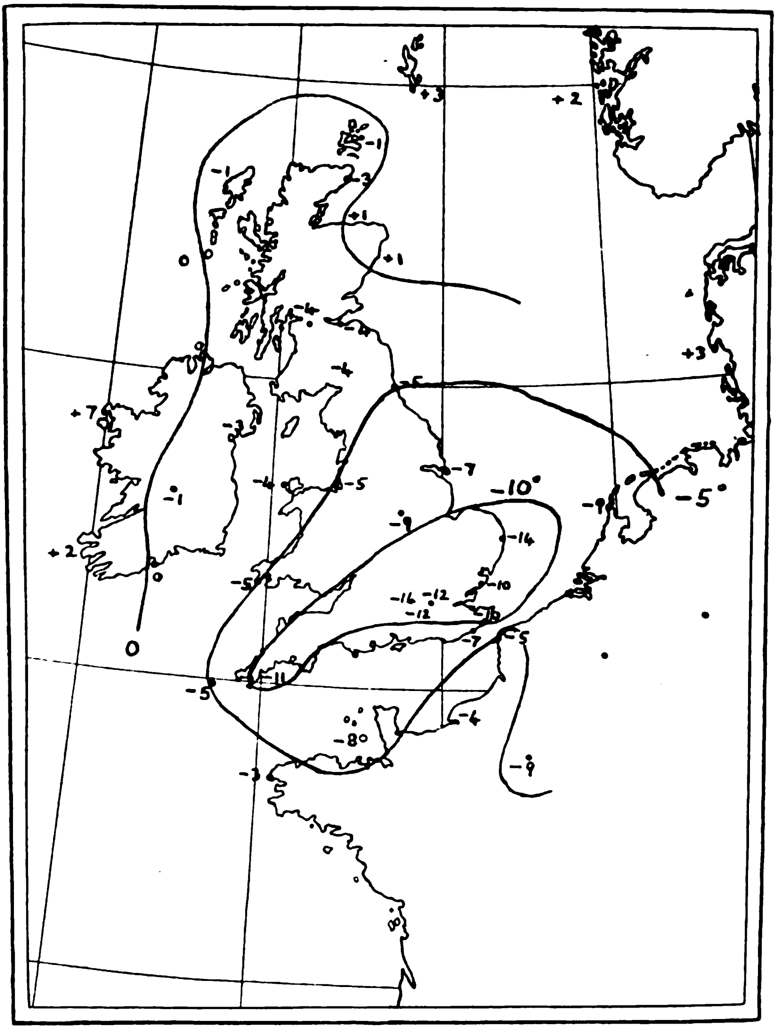

FIG. 2.—Change of Temperature between 7 h. and 18 h., Feb. 16, 1916.

STORMS NOT OF THE LINE-SQUALL TYPE.

1916. *March 13th.*—A storm coming from the Channel reached Sussex and Kent about 18 h. and moved slowly north or north-west. There was very frequent lightning, but the thunder was not loud even in places where the storm passed overhead; this indicates that the flashes were from cloud to cloud, as in certain types of summer storms; there was no record of a fall of temperature. The wind was Easterly in most places, but went round to South in some localities. The 18 h. map shows an East wind over England and a South-West wind in France; at Oxted the surface wind was North-East but the clouds came from South-West. Tempera-

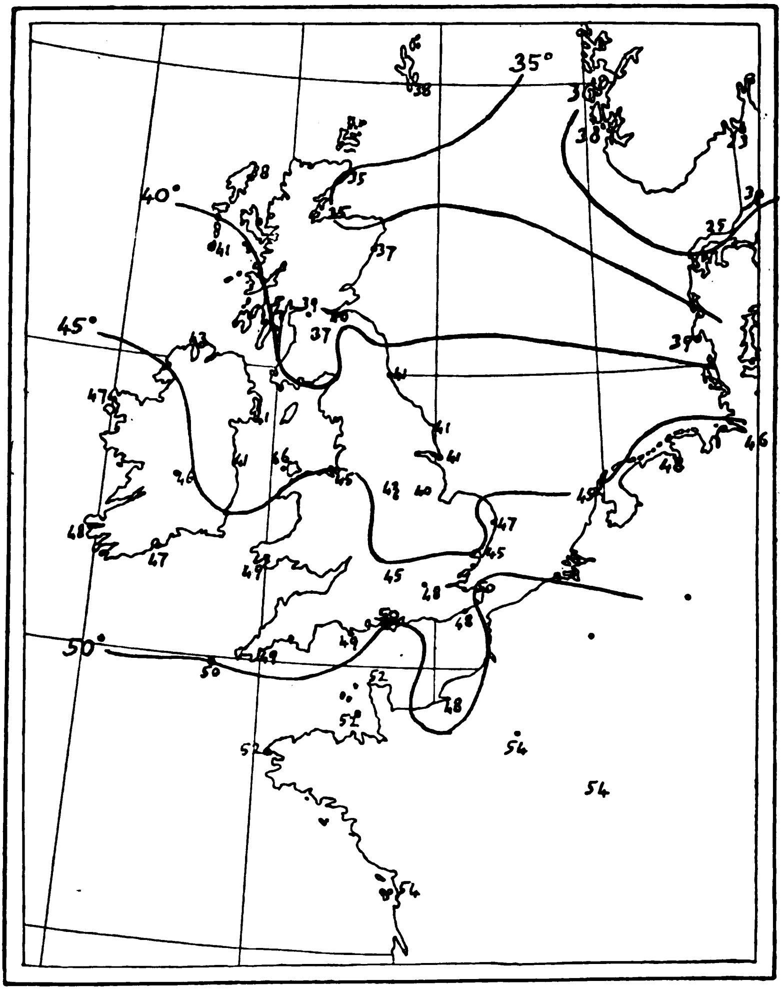

FIG. 3.—Temperature at 18 h., Jan. 11, 1920.

tures over S.E. England were 41° F. at 18 h.; Havre was 48°, and at Paris, where the wind was South-West, the temperature was as high as 54°. This storm was almost certainly due to a warm current rising over a cold one (Fig. 4).

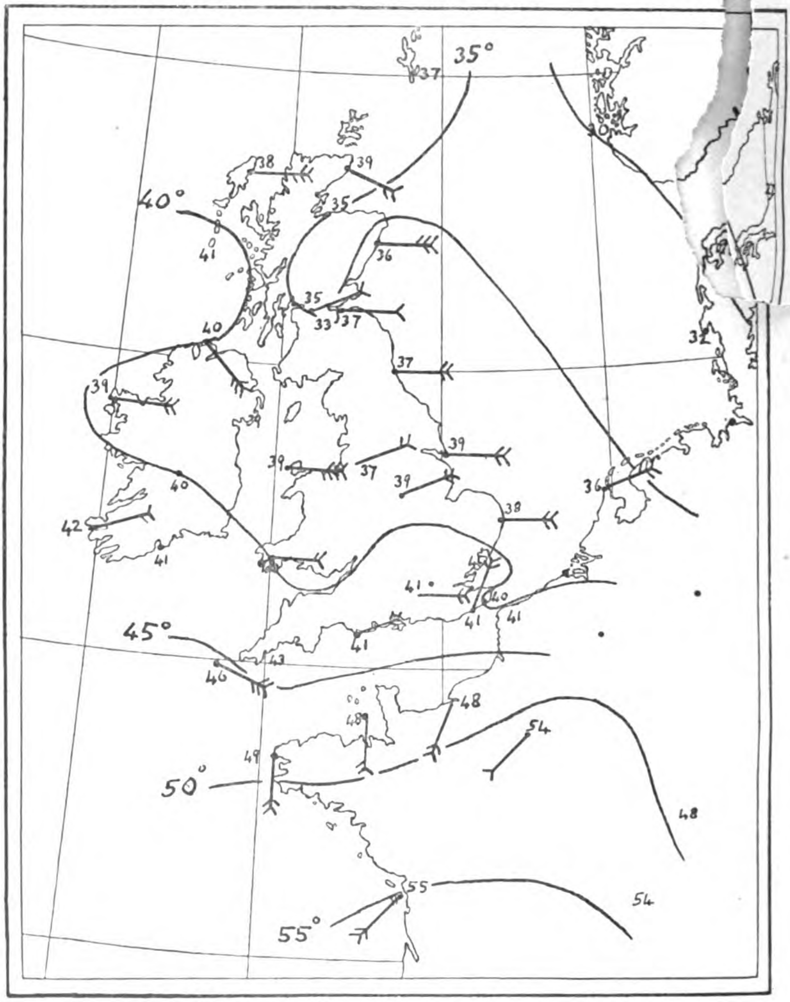

FIG. 4.—Temperature and Wind at 18 h., March 13, 1916.

March 14th.—Jersey; the storm commenced at 18 h. and continued till 5 h. on the 15th. There was a fairly steep temperature gradient across the Channel: Jersey 52° F., Portland Bill 45°. This storm, like the one of the previous day, was almost certainly due to a warm current rising over a cold one. Southerly winds are found in the South of France.

1918. *March 14th.*—A very local storm near Chipping Norton in Oxfordshire at about 23 h., which occurred when the British Isles were under the influence of an anticyclone which was centred over southern Scandinavia.

GENERAL BAROMETRIC SITUATION.

In general it seems that the greater number of winter thunderstorms occur when deep depressions are found to the north of the British Isles, either with secondaries passing over the country or with straight isobars; probably in the latter case there are small irregularities in the isobars, which are too small to be shown on the ordinary isobaric charts but which are responsible for the thunderstorms.

THE CAUSE OF THUNDERSTORMS.

Mr. E. V. Newnham[1] says that the formation of thunderstorms in summer is due to "instability over a height of several thousand feet caused by a suitably rapid fall of temperature with height"; this of course is generally admitted. He goes on to say "that in many instances the powerful heating of the lower layers of the atmosphere by the sun is mainly responsible in bringing this about. It seems reasonable to suppose that in winter also instability is in general essential, but, solar radiation being relatively feeble, it can only be the heat imparted by the warm ocean to the lower layers of the cold currents of air which is likely to give rise to conditions analogous to those accompanying thunderstorms in summer. Storms should, therefore, seldom occur in air that has not come from very cold regions and subsequently crossed a considerable stretch of ocean."

The method of drawing trajectories, adopted by Newnham, to find out the place of origin of air on occasions of winter thunderstorms is not feasible in the cases discussed in this paper, for, owing to the war, the necessary material is not available. But on the whole it appears that most of the thunderstorms occurred when masses of air at different temperatures were in close juxtaposition. The actual instability would occur with cold air undercutting warm air or with warm air rising over colder currents. On either theory we should expect to find that some of the air, the cold current, had come from very cold regions, but on Newnham's theory one would not necessarily expect to find very warm masses of air close to the cold air, as from the present investigation seems on the whole to be the case.

To sum up, it seems that there may be at least four causes of instability and resulting thunderstorms.

1. Actual heating of the ground, and consequently of the lower layers of the atmosphere by the heat of the sun, on occasions when the lapse rate is large. This would seem to be the cause of the thunderstorm of the summer afternoon, and especially of those thunderstorms which occur on several days in succession; possibly it is also the cause of some of the thunderstorms associated with April showers.

2. The flow of comparatively cool air in the middle layers over a warm region, which gradually increases the lapse rate by cooling above,

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[1] *Meteor. Off.*, *Professional Notes*, No. 29, M.O. 245*i*.

till instability occurs. This seems to be the cause of storms, especially in summer, which occur after a period of heat when shallow depressions approach from the Atlantic. These storms come up from the west in many cases with a surface wind from a widely different direction. The storms which occur on summer nights are probably due to this cause, and these, too, are the storms whose approach is heralded by clouds of the alto-cumulus-castellatus type, clouds which indicate instability in the middle layers of the atmosphere before it has reached the lower layers.

3. Warm air rising over a colder wind current. Storms due to this cause often take place in the north-east quadrant of a depression and are often associated with heavy and long-continued rainfall. If the depression with which they are associated travels slowly the locus of the instability may not change rapidly, and these storms often endure for many hours. They usually occur with a wind from some Easterly point, but if a break in the lower cloud sheet occurs, an upper current from a Southerly or Westerly point may be revealed by the motion of a higher level of cloud. The storm of March 13th, 1916, and those of the two following days at Jersey, seem to be of this type. To the same class belong also the severe storms which occur in a col between two anticyclones, and in general those storms which occur when light winds from different directions and of different temperatures are found in close proximity; a typical example of the latter kind of storm was that which occurred on March 11th, 1912, in Hampshire and Sussex.[1]

4. The undercutting of warm air by a colder current. This may occur when masses of warm air and cold are in close proximity and when strong winds are blowing, occasioning short local storms, or when a large mass of cold air invades a warm region occasioning a more or less widespread line squall. Most of the storms noticed in this paper, in fact the great majority of winter thunderstorms, and some summer storms, seem to belong to this class.

I take this opportunity of thanking the many observers, too numerous to name individually, for their kindness in sending in the reports that have made it possible to write this paper.

DISCUSSION.

Mr. E. V. NEWNHAM in a written communication: Although line-squalls are often accompanied by thunderstorms both in summer and in winter, I think Mr. Cave's paper contains evidence that the majority of storms in the British Isles do not arise in this way. Line-squalls, unlike thunderstorms, do not appear to occur much more frequently on our north-west coasts than elsewhere. Moreover, the line-squall is a comparatively rare phenomenon, the thunderstorm a very common one, even in winter, as Mr. Cave has himself so well shown, and I do not see, therefore, how the former can in the large majority of cases accompany the latter. Further, when westerly winds from the neighbourhood of Greenland are crossing the British Isles, thunderstorms generally occur, as I pointed out in *Professional Note* No. 29,[2] but contrasts of temperature at the surface are often unusually small at such times. This point is one to which I devoted some attention, previous to writing the paper just referred to.

As regards the general conditions immediately preceding the most widespread outbreaks of thunderstorms in mid-winter, I found these to be the persistence for twelve hours or longer of an unusually deep depression off the Hebrides—a situation particularly favourable for the arrival of polar air that has crossed warm water. I did not notice any particular tendency for straightness in the isobars on these occasions, and concluded that this is a phenomenon accompanying as a rule only those thunderstorms that are associated with the passage of a definite line-squall across the country.

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[1] See *Q. J. R. Meteor. Soc.*, 38, 1912, p. 275.

[2] M.O. 245*i*.

Mr. C. E. P. **Brooks** said that one important piece of evidence in favour of differences of temperature as causing winter thunderstorms was the very rapid gradient in the number of storms as one passed inland from the western coasts to the interior. Taking the six months October to March, there are on the average four or five storms on the coast, while fifty miles inland the number drops to one or two. If the number of storms in the winter half-year were expressed as a percentage of the annual total, it increased from more than 30 per cent, in some cases more than 50 per cent, on the coast, to less than 5 per cent fifty miles inland.

Mr. C. J. P. **Cave**, in reply to Mr. Whipple, said he thought that most of the days with one report were occasions of local storms probably of the line-squall type. He could not reply to Mr. Newnham without a further study of his remarks. Probably if there were any thunderstorms during the coming winter it would be possible to discriminate between Mr. Newnham's ideas and those set forth in this paper.

FORECASTING SKY-TYPES.

By D. E. ROW, F.R.Met.Soc.

[Abstract of a paper read before the Society on December 20, 1922.]

THE object in view in attempting to forecast sky-types was to facilitate painting views in selected weather conditions, or "skies," themselves decided on beforehand. The principle employed was very similar to that used in ordinary forecasting, viz., the type of pressure distribution as shown by a map, or suggested by the "Further Outlook" of the Meteorological Office, and the part of it which is likely to affect the locality concerned, using local indications in conjunction therewith.

To quote one or two broad examples to amplify the above:—Cirrus types followed by cumulus forms are to be expected during the passage of depressions, or even where overlapping occurs between an anticyclone and a depression.

Indefinite areas of low or medium pressure often give very composite skies, thus yielding striking cloudscapes in which a large variety of cloud types is featured simultaneously.

The pictures illustrating the paper (not reproduced) *are purposely semi-impressionist and therefore not intended to be viewed closely.* They are actual results of observation and forecasting of selected types of weather, and as considerable distances had to be covered in order to obtain the views, confidence in one's predictions was highly desirable.

It was submitted that if an artist possesses a good knowledge of the characteristics of the various types of pressure distribution and can use local signs in conjunction therewith, he will be able to regulate his movements with far greater intelligence and accuracy than would be the case if he simply took "pot" luck founded on ignorance.

It is hoped to extend and improve the use of the principle outlined above.

ANCHOR-ICE.

[Abstract of a paper by Prof. W. J. ALTBERG entitled "A Contribution to the Study of Anchor-Ice and of the Infra-red Absorption Spectrum of Water."]

UNDER certain conditions ice is formed at the *bottom* of rivers and on submerged objects below liquid water ("frazil" or "anchor" or "ground" ice). The physical process of the formation of ice in this remarkable position was not known, but Barnes and others put forward the theory that water was transparent to radiation of a wave-length in the neighbourhood of 10 μ. Since this is about the position of maximum radiation for a black body at about 273° a., Barnes suggests that the bottom of the river is cooled below the temperature of the water by outward radiation which passes nearly unabsorbed through the water above it.

The object of the present paper is to disprove Barnes's theory. A review of the measurements of the absorption coefficient of water by Paschen, Rubens, Aschkinass, and others, makes it quite clear that there is no wave-length in the infra-red for which water has not a high coefficient of absorption. It is shown that 1 cm. of water would cut off all appreciable radiation from a body at 273° a.

Barnes's theory is thus shown to be wholly untenable.

ON THE CAUSE OF THE FORMATION OF ICE AT THE BOTTOM OF RIVERS AND LAKES.

By W. J. ALTBERG, Senior Physicist, Central Physical Observatory, Petrograd.

THE explanations hitherto proposed, of the causes to which the formation of ice at the bottom of bodies of water is due, being unsatisfactory and insufficiently supported by facts, have induced the author of the present communication to submit the whole problem to a radical revision. The occasion for coming to this decision was offered by a most unusual case of the freezing of the river Neva on December 14, 1914, when the bed of the river at a depth of 20 metres was covered with a continuous sheet of loose ice 0·76 metre thick. According to the testimony of the divers who repeatedly descended under water in the course of the day, not only was the bottom covered with a thick layer of ice, in which the divers sank above their knees, but a similar covering enveloped all the objects resting on it, and among them various appliances of the Petrograd Water Works, such as chains, the ladder and landing-place attached to the receiving apparatus, and the wide apertures (d. = 2·0 metres) of the receiving pipes themselves, which latter circumstance caused an interruption in the water supply to the town.[1]

The divers stated that the receiving funnels (with the gratings) had been covered as it were with an "ice cap." The thickness of the ice exceeded 0·6 metre. The task of clearing the grating from ice took many hours and was accomplished successfully, to which contributed in no small degree a decided improvement in the weather and a rise in the temperature of the air and water.

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[1] The water pipes laid on the river bed (d. = 1·2 metres) are turned up at their ends to a height of 3·7 metres, being there bent at right angles and terminating in wide funnels, which open downstream. In order to prevent the pipes from being choked their wide mouths are protected by gratings, on which ice forms almost annually.

At the suggestion of the Water Works Commissioner, I undertook a series of investigations at the Laboratory of the Central Physical Observatory and conducted outdoor observations with relation to this phenomenon. The object of the laboratory work was to attempt to reproduce the phenomenon by artificial means, which I succeeded in accomplishing as early as in 1915, after which I was enabled by experimental means to determine the importance and share of each of the factors involved in the processes of the cooling of water and its transformation into ice. The results obtained I published at the time in Russian periodicals.[1] In this article I intend to give but a general summary of these results and of the inferences made.

Extreme care was taken in measuring the temperature of the water in the river in autumn, especially during the period of the appearance and formation of ice. For that purpose the following instruments were used: (1) mercury thermometers (specially mounted), scaled to 0°·01 C.; (2) Callendar's electrical thermograph (with a sensitivity of 0°·02 C.); (3) an instrument specially devised (microthermometer) for measuring temperature in the river itself (with a sensitivity of 0°·001 C.). The measurements were always taken with all possible precautions and with the requisite care at various depths throughout the length and breadth of the river.

It has appeared, that the river water during the drifting of the ice was supercooled both at the surface and at the bottom, as well as in the intermediate layers. The amount of supercooling was usually small, and would generally vary between 0°·001 C. and 0°·01 C., rising in exceptional cases to as much as 0°·1. During the period mentioned there commonly occurred the formation of loose ice under water, on submerged objects, and sometimes on the bottom. Fig. 1 reproduces the temperature chart of the Neva for November 1916.[2] On November 21, 22, and 23, and partly on the 17th and 24th, the water was supercooled; on the same days occurred a copious formation of anchor-ice, which was likewise carried down by the current into the wells of the Water Works. Fig. 2 represents the variation in the temperature of the Neva according to hourly observations taken day and night in December 1920 with the

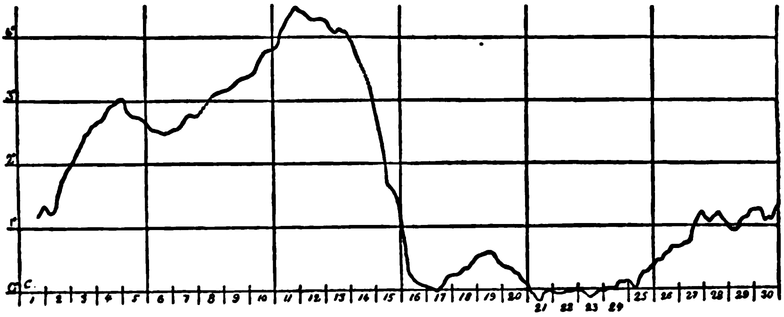

FIG. 1.—Temperature of the river Neva, November 1916.

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[1] *Geophysical Journal*, vol. iii., parts 1 and 2, 1916. *Izvestia* of the Central Physical Observatory, vols. i., ii., 1920, and iii., 1921.

[2] The receivers of Prof. Callendar's electrical thermographs (specially ordered from London for the purpose) were securely fixed at a depth of 10·7 metres.

mercury thermometer (sensitivity of 0°·003 C.). In 1921 with the microthermometer was found:

8th November, 14 h. 15 m., – 0°·032 ± 0·002.
10th November, 7 h. 5 m., – 0°·024 ± 0·002.

During supercooling loose ice was invariably formed. The curves (Figs. 1 and 2) show that this supercooling of the river, notwithstanding the presence of ice, may continue for hours and even days. It is important to draw attention to the fact that the water remained in the supercooled condition *in the presence of the solid phase.* This circumstance, as well as the fact of the supercooling of the water, was submitted to the most careful tests in many experiments on the cooling of water, which were conducted in suitable vessels in which the water was continuously stirred. The readings were taken with Beckmann's thermometer (with a sensitivity of 0°·002). A typical course of the variations in the temperature of water is exhibited in Fig. 3.

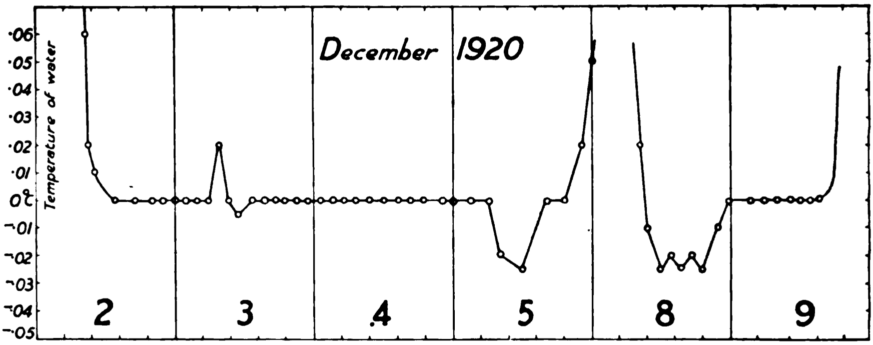

FIG. 2.—Temperature of the Neva, December 1920.

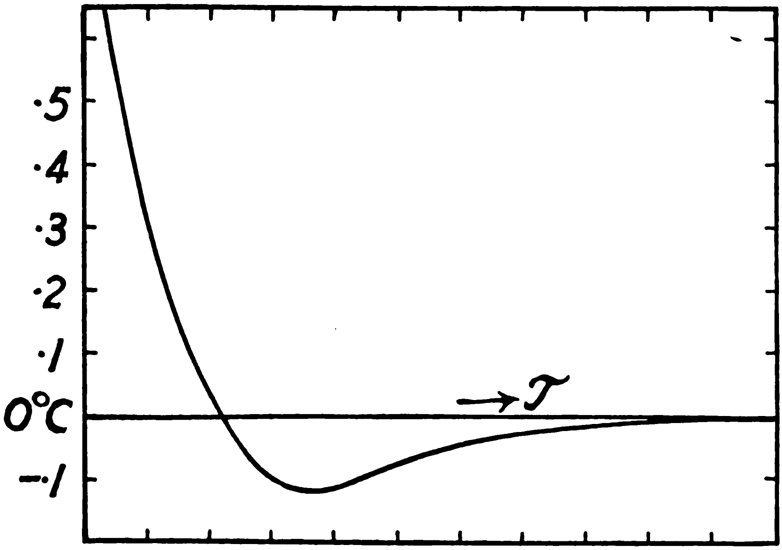

FIG. 3.—Typical curve showing variations in the temperature of water.

Further experiments confirmed that:

1. Water invariably assumes a slightly supercooled condition, irrespective of its coming in contact with snow or not.

2. A maximum degree of supercooling is always observed during the first half of the period of supercooling; crystallization likewise occurs in this half.

3. The degree of supercooling substantially decreases during the second half of the period and becomes inconsiderable.

4. Notwithstanding a copious formation of ice at the time, the supercooling process is maintained for a *protracted* period. Hence comes the conclusion, that by the mere contact with the solid phase water is not always brought to the precise temperature of 0° C., and conditions are conceivable when deviation from rules, formerly universally acknowledged, may occur; so in my experiments on the artificial reproduction of the phenomenon of anchor-ice, lasting for six hours or more, the water retained its supercooled condition for hours.

Monti's experiments, repeated in collaboration with M. T. Penkewitsch by myself, show that water may be supercooled not only by its being gradually cooled in a state of complete quiet, but also by being cooled *rapidly* and *stirred* continuously. It therefore follows that the essential condition for the transition of water into the supercooled state does not consist in the slow process of cooling and a condition of rest, but in something else. Numerous experiments lead to the conclusion that that condition lies in preventing the water from coming in contact with the solid phase, in the presence of which crystallization setting in after a cooling to the temperature of 0° C. should debar the water from being supercooled.

The results of these experiments, as regards both the amount of supercooling and the capacity of retaining the supercooled condition in the presence of the solid phase, are in complete accord with what has been observed to occur in natural conditions, as stated above. In rivers, an amount of supercooling of water of the same order of magnitude as that given above has been likewise established by a number of independent investigators.

The distribution of the temperature of the water in accordance with the profile of the river was next submitted to the most careful investigation. It then appeared that although in rivers the temperature was as a rule evenly distributed in various depths, still this uniformity was but approximate. In view of an incomplete or rather insufficiently thorough intermixing of all the layers of the water, deviations in temperature from the mean are observed, generally varying from 0°·01 to 0°·1 C.[1]

This occurs not only in the warm season but also in autumn, when the temperature of the water approaches 0° C. Deviations from the isothermal condition both in the positive and in the negative sense are distributed in the river's profile in a very arbitrary manner, being subject to no definite rule, even frequently defying the statically stable distribution of densities, so that the colder, and therefore the lighter, layers are not infrequently disposed below the warmer and denser strata.

From a large number of observations of this kind hourly readings of the temperature of the water in the Neva are given in the table below for November 8, 1915, at depths of 0·05, 0·5, 1·0, and 2·0 metres.

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[1] A stricter uniformity in the distribution of temperature occurs only in the river's rapids, where the intermingling of the water is so complete that the deviations from the mean temperature of various points in the profile of the river do not exceed 0°·001 or 0°·002 C.

Such results of observations, taken during the formation of ice, exhibiting the causes and the likelihood of the occurrence of supercooling of the inner and even the bottom layers of water, tend to remove one of the many obstacles that have hitherto hindered a proper understanding of the phenomenon of anchor-ice.

The very slight degree of the supercooling of water, as manifested at the bottom and at other points of the river's profile, is far from sufficient to maintain the process of crystallization, for the heat emitted during the process may check supercooling and retard crystallization. The latter can only be effected if there is a continuous removal of the heat evolved in the process of crystallization, which is proportionate to the quantity of ice formed (80 gramme calories per 1·1 gramme of ice). Thus the key to a true interpretation of the phenomenon lies in the mechanism of the transmission of heat from the bottom to the surface, which, as I had already shown in my former article, cannot be produced by radiation from the bottom, the water being completely opaque to such radiation, the more so as we have here to deal with a powerful displacement of heat attaining, according to Homen, 1000 gramme calories a day from an area of water of 1 cm.^{2} on cold days in autumn.

8TH NOVEMBER 1915.

TIME.	Depth in cm.			
	5.	50.	100.	200.
Hrs.	° C.	° C.	° C.	° C.
1	0·08	0·10	0·07	0·09
2	0·06	0·06	...	0·05
3	0·04	0·05	...	0·06
4	0·09	0·11	0·12	0·11
5	−0·01	−0·01	−0·04	−0·02
6	−0·01	−0·01	−0·03	−0·02
7	−0·01	−0·01	−0·02	−0·01
8	−0·01	−0·01	0·05	0·00
9	−0·01	−0·01	0·05	0·01
10	−0·01	−0·01	0·05	0·03
11	0·02	0·03	...	...
12	0·04	0·06	0·13	0·10
13	0·00	0·01	0·05	0·07
14	0·00	0·01	0·03	0·02
15	0·01	0·02	0·05	0·03
16	−0·01	−0·01	−0·02	−0·01
17	0·00	0·02	0·01	0·00
18	−0·01	0·00	−0·05	−0·04
19	−0·01	0·01	0·01	−0·02

In view of the continuously maintained (approximate) uniformity of the temperature in the body of the water, so vast a loss of heat is not only confined to the superficial layer of water, but in an equal measure extends to all the remaining layers. The mechanical intermixture of the layers thus maintains an energetic exchange of heat between the bottom and the surface, and affords the means for a *continuous* supercooling and therefore for an *uninterrupted* process of crystallization. In this circumstance lies the whole root of the matter.

In analysing the causes of the two, now historical, cases of the formation of vast masses of anchor-ice in the Neva in Petrograd (in 1894 and 1914), I came to the conclusion that the very rare combination of favourable conditions which had occurred in the two years aforesaid, and which had caused a loss of heat by water maximal in its intensity —this combination was alone responsible for the circumstance that the Neva commenced to freeze from underneath and thus cut off the town's water-supply.

In order definitely to establish the fact that the formation of ice does not depend upon radiation, as was thought by Barnes, and is not effected by the introduction of ice from the surface, as is affirmed by Aitken, I made an experiment on the formation of ice under conditions which precluded the possibility of ice gaining access from the surface and of the bottom taking any part in the process. My experiment was conducted in the following manner:—A glass vessel filled with water, and with stones on the bottom, was placed during two or three days in a room with a constant temperature of about $-0^{\circ}\cdot1$ C. After the introduction through a pipe of a small piece of ice, the water was for some time well mixed together and then left in peace. It was soon possible to perceive on the surface of the stones at first the appearance of separate elements of ice and their growth, and the stones were subsequently completely covered with a layer of loose ice very like moss, while the water during all that time remained perfectly still.

The artificial reproduction of the process of the formation of a primary layer of anchor-ice under conditions fully excluding the access of ice from the surface and any share that might be taken in the phenomenon by the radiation of heat from the bottom, thus emphatically indicates the direction in which the cause of the phenomenon is to be sought. And in rivers the mechanism of the formation of the primary layer on the bottom is obviously the same as in the artificial reproduction of it; its further growth would proceed in either or both of the following ways:

1. By means of the immediate growth of the crystalline elements at the expense of the supply of cold continuously furnished by the flowing supercooled water, which would then carry away with it the heat produced by crystallization (as has been proved by experiments artificially reproducing the formation of anchor-ice).

2. By means of an extensive accumulation and adhesion (due to regelation) of fine particles of ice always found in water. The accumulation of ice by this last means is also unconditionally admitted by Barnes and other investigators.

Owing to long experience, lasting many years, based on observations on anchor-ice in its natural conditions and on numerous reproductions of the phenomenon made in the laboratory, the substance of the phenomenon has become perfectly clear to me, leaving no room for any doubt and devoid of any vestige of paradox.

Thanks to this experience, I was at last able in a large majority of cases to foretell the occurrence of the phenomenon in question, as also where and when it would happen. The causes of the occurrence of anchor-ice, as mentioned above, on the historical occasions in the Neva are perfectly clear to me, as are those of the rarity of the phenomenon in some bodies of water and its frequency in others.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

NOVEMBER 22, 1922.

Special General Meeting.

This meeting amended By-law 6, which as amended runs as follows :—

6. Every person desirous of admission into the Society as a Fellow, must be proposed and recommended in the terms of the Form No. 1 in the Appendix, which form must be subscribed by at least three Fellows, one of whom must certify his personal knowledge of the candidate. *But persons may be proposed and recommended by the Council, and this By-law shall not apply to such persons.*

[The amendment is the addition of the sentence shown above in italic type.]

At the *Ordinary Meeting* on November 22, 1922, the following candidates were balloted for, and elected Fellows of the Society :—

FRANCIS GEORGE ASHBY, Accra, Gold Coast, West Africa ;
Prof. GARNET HOMER CUTLER, University of Alberta, Edmonton, Canada
ARTHUR FARRINGTON, Landsdowne House, Apollo Bunder, Bombay ;
MAHMUD HAMED EFFENDI, B.Sc., Physical Department, Cairo, Egypt ;
HAROLD JOHN HOLMES, 10 Southsea Avenue, Watford, Herts. ;
Major JAMES MECREDY MACLULICH, 23 Oriental Place, Brighton ; and
JOHN WILLIAM SANDERSON, A.M.I.M.E., 13 Norwood Street, Normanton, Yorks.

Messrs. Ball, Baker, Cornish & Co., Chartered Accountants, were appointed Auditors of the Society's accounts for 1922.

At the *Ordinary Meeting* on December 20, 1922, the following candidates were balloted for, and elected Fellows of the Society :—

HAROLD JAMESON, B.Sc., The Observatory, Colombo, Ceylon ;
NEVILLE RUSSELL SWALES, Lieut. R.E., Brompton Barracks, Chatham ;
CECIL MUSGRAVE WARREN, 69 Holton Road, Barry Dock, S. Wales ; and
ROGER ALAN WATSON, B.A., 32 Cartwright Gardens, W.C.1.

OBITUARY.

Sir THOMAS GLEN-COATS, Bart., C.B.

Sir Thomas Glen-Coats, Bart., died on July 12 at Ferguslie Park, Paisley, at the age of seventy-six.

He was a member of the family famous for the foundation of the well-known firm of thread-makers which has been established in Paisley for so many years, and was the second son of Thomas Coats of Ferguslie and Maxwelton.

Apart from his business life, Sir Thomas was a man of varied interests and noted in Glasgow for his philanthropic disposition.

He became a member of the Scottish Meteorological Society in 1898, and transferred to this Society at the time of the amalgamation in January 1921.

Dr. C. G. KNOTT, D.Sc., LL.D., F.R.S.

Cargill Gilston Knott, who died suddenly on October 26, 1922, had rendered great services to mathematical and physical science. Born in 1856, he entered the University of Edinburgh in 1872, when Tait was in the fulness of his powers, and at once fell under the influence of that great teacher. A natural aptitude for research work, high mathematical talents, and amazing industry led to intimacy with Tait, whose assistant he became in 1879. Proceeding to Tokyo in 1883 as Professor of Physics, he remained for eight inspiring years in Japan, conducted a magnetic survey of that country, and, along with John Milne, helped to found the modern school of seismology, of which his own pupil, Omori, is a leading exponent. From 1891 until his death he had charge of the department of Applied Mathematics in the University of Edinburgh, latterly with the title of Reader.

Knott's research papers are very numerous, and a recent series dealing with the theory of earthquake-wave propagation is of special importance. His devotion to seismology found expression in *The Physics of Earthquake Phenomena* (Oxford, 1908). His *Life of Tait* (Cambridge, 1911) is a memoir of absorbing interest, and the Napier tercentenary volume (1914), edited by him, is an admirable production.

Knott's interest in meteorology was lifelong. He became a member of the Scottish Meteorological Society in 1900, served for many years on its Council, and was President at the time of the Society's amalgamation with the Royal Meteorological Society two years ago. A volume of the collected papers of the late Dr. John Aitken, F.R.S., had very recently been prepared and passed for press by him.

Knott stood in Edinburgh for "natural philosophy" in the sense in which Forbes and Tait had interpreted it; but his sympathies were very wide, and as Secretary, during the past ten years, of the Royal Society of Edinburgh he was in touch with workers in all branches of Science. Life was for him a very full and rich thing. He took a large part not only in the scientific but in the social and artistic life of the Scottish capital, and his many friends will remember him as "an unselfish, modest Christian gentleman, whose life was a constant round of unobtrusive service."

Mr. LESLIE STUART PRIESTLEY, B.A.

Mr. L. S. Priestley began his meteorological career in August 1921 by joining the Shoeburyness Staff of the Meteorological Office. That part of the work of the station appertaining to the kite balloon and its equipment was placed under his charge, and he entered upon these duties at a time when a number of new and experimental accessories were being given a trial with a view to incorporation in the permanent equipment of a meteorological kite balloon station. He was conspicuously successful in organising this department of the work, and a number of his suggestions were definitely embodied in the methods used in handling a kite balloon and its meteorological instruments. He had been engaged on this work for six months when he was seized with the illness from which he died on September 3, 1922, at the age of twenty-five years.

During the war Mr. Priestley served in the Royal Garrison Artillery, and he had the misfortune to be gassed. His untimely death was undoubtedly due directly to the weakness left behind as a result of the gas poisoning from which he suffered on that occasion.

Mr. Priestley was elected a Fellow of this Society in December 1921. Apart from his official duties, he was a man of many social activities and an active participator in outdoor sport.

REVIEWS.

Klima-Atlas von Deutschland. Bearbeitet von G. HELLMANN, und den Observatoren G. von ELSNER, H. HENZE und K. KNOCH. Berlin, Preussisches Meteorologisches Institut, 1921. Veröff. No. 312. Dietrich Reimer (Ernst Vohsen) A. G. Fo. Pp. 40, charts 63. Price £1 : 15s.

Climatological Atlas of Germany.

At the end of 1911 the Society discontinued the collection and reduction of climatological observations and their publication in the *Meteorological Record*, and proposed instead to undertake the critical examination of the vast amount of data already available, with a view to the publication of a comprehensive Climatological Atlas of the British Isles. An outline of the scheme, together with some of the draft maps, was laid before the Fellows at the Annual General Meeting in January 1915.[1] Unfortunately the difficulties in the way of realising our ambitions have proved greater than we anticipated, and for the moment the project is in abeyance. It is therefore a matter of considerable interest, not entirely dissociated from feelings of envy, to see how another institution in another country has tackled—and solved—a similar problem. The Climatological Atlas of Germany, a copy of which has recently been received for the Society's library, has been prepared in the Prussian Meteorological Institute under the personal supervision of the Director, Geheimrat G. Hellmann.

The Atlas consists of 63 plates and 34 pages of tables, the explanatory text being confined to 6 pages of letterpress. The size of page measures 14 by 12 inches, only slightly larger than the quarto size (12×10) contemplated for our own atlas. This admits of maps covering the area of the Empire as it existed in 1914 on the scale of $1 : 4{\cdot}25 \times 10^6$, slightly larger than that used for the rainfall maps in the *Monthly Weather Report* of the Meteorological Office ($1 : 5 \times 10^6$) which we propose to use. The majority of the maps are on this scale, but the half scale $1 : 8{\cdot}5 \times 10^6$ is used for the representation of humidity and vapour pressure and in a few subsidiary maps. The monthly maps of rainfall are on the scale $1 : 2{\cdot}5 \times 10^6$ necessitating the use of folding plates, while the map of annual rainfall is on the scale $1 : 1{\cdot}8 \times 10^6$. For purposes of orientation the courses of the principal rivers and the positions of selected towns are shown. Elevations are indicated on the maps of temperature and cloud amount by light shading.

The period of 30 years from 1881 to 1910 has been adopted as the standard for most elements, and incomplete series of observations have been adjusted to this period by the usual method of comparison of neighbouring stations. The principal exception is furnished by the rainfall data for which the shorter period of 20 years, 1893 to 1912, has been used.

The first 14 plates show the distribution of monthly and annual averages of mean temperature reduced to the mean sea level, and of the annual range of temperature expressed as the difference between the means for the warmest and the coldest months. The representation is by means of isotherms drawn for intervals of 1° C. The practice of computing the mean temperature from a combination of maximum and minimum, generally adopted in this country, has not been followed. Instead, the means are computed from combinations of the observations at fixed hours, occasionally supplemented by the minimum temperature, such as $\frac{1}{4}$ (7 h. + 14 h. + 2 × 21 h.) or even by such complicated combinations as $\frac{1}{3}(8\text{ h.} + 14\text{ h.} + 20\text{ h.}) - c\left(14\text{ h.} - \frac{8\text{ h.} + 20\text{ h.}}{2}\right)$, c being a factor which varies with the months. As the hours of observation have not been the same throughout the period under review, or over the whole empire, various combinations have had to be used to secure comparable results. The tabular matter referring to temperature is considerable. Table 1 gives the monthly and annual means for over 300 stations; Table 2 the mean daily maxima and minima for 229 of these; Table 3 the mean of the monthly maxima and minima and the absolute extremes for the year for a still smaller selection of stations. Table 4, which gives for selected stations the average number of ice days, *i.e.* days on which the maximum temperature failed to rise above the freezing point; days of frost, *i.e.* days on which the minimum fell below the freezing point, and of summer days, *i.e.* days of maximum temperature of 25° C. (77° F.) or above, forms a useful addition to the information regarding temperature. Finally, Table 5 gives 5-day means of temperature for a selection of stations.

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[1] *Quarterly Journal*, **41**, 1915, p. 148.

Plates 14 to 27 are devoted to the representation of pressure and the mean direction of the wind. Isobars are drawn for intervals of 0·5 millimetre, 0·25 in the case of May which is characterised by extraordinary uniformity of pressure over Germany. The mean wind direction is computed by Lambert's formula, the length of the wind arrows being varied to give an indication of the steadiness of the wind. The tabular part of the book contains no pressure data, but the somewhat incomplete picture of the winds presented by the mean directions is supplemented by a table of monthly percentage frequencies of the eight wind directions for selected stations. We are not surprised to read that the attempt to construct charts showing lines of equal wind velocity had to be abandoned. Anemometer stations are too few, and, moreover, differences of exposure make a strict comparison of the available data unsatisfactory. The only information on wind velocity is contained in a table giving the monthly and annual mean velocities for 30 stations.

Plates 28 to 33 give, on the smaller scale already referred to, the distribution of vapour pressure reduced to sea level and the relative humidity at station level, the corresponding numerical values being given in Tables 8 and 9. On Plate 34 we find the annual values of these elements, while the two remaining maps are used for showing the distribution of the average annual number of days of clear sky and of overcast sky. Plates 35 to 47, in which the normal scale is resumed, are given over to the representation of the mean amount of cloud on the scale 0—10. The cloud charts are followed by the 12 charts of the monthly distribution of precipitation and the large scale map of annual precipitation. The annual map is based on observations from about 3600 stations, of which nearly one-half have complete records for the adopted 20-year period 1893 to 1912. The adjusted totals for the whole set of stations are given in Table 13. The monthly maps of precipitation have been constructed from the annual map by a process somewhat similar to that which it is proposed to carry out in our own atlas, details of which were given in a paper recently read before the Society by M. de C. Salter. The monthly averages for the stations having complete records were first worked out as percentages of the annual totals. The results are given numerically in Table 14, which also shows the monthly *rainfall coefficient* in which allowance is made for the unequal length of the months. The stations were then arranged in 57 groups according to types of seasonal variation, and an average monthly percentage factor calculated for each group. These group-percentage factors were then applied to the adjusted annual averages for the stations possessing incomplete records in order to arrive at the averages for individual months on which the monthly charts are based. Two plates showing the annual average number of days of precipitation for which the limit is taken at 0·1 mm., and the average number of days of snow, which yielded at least 0·1 mm. of water when melted, follow, and the pictorial matter is completed by a plate of four maps on the smaller scale showing the distribution by districts of the driest and wettest months, and the months of maximum and minimum number of rain days.

There are no maps showing the distribution of sunshine, the number of stations being insufficient to justify their construction, and, moreover, the available data are not considered sufficiently homogeneous. Such information as is available is conveyed in a table giving the mean daily duration and the percentage of the possible for each of the 12 months, and for the whole year for about 50 stations. The final table gives for a selection of stations the average number of days of thunderstorms for the whole year, but it was not practicable to represent this information cartographically.

The *Atlas* is admirably got up, printing, lithography, and quality of paper leave nothing to be desired. We congratulate the Prussian Institute on the accomplishment of a most useful but extremely laborious task.

Études élémentaires de météorologie pratique. By ALBERT BALDIT. Paris (Gauthier-Villars et C^{ie}), 1921. 8°. Pp. ix + 347. Price 15 fr. net.

I recollect arriving one evening in August 1918 at Châlons-sur-Marne, meeting women and children trooping out of the town to shelter from the anticipated bombs of the night. I had gone there to see the most important meteorological station of the French Military Meteorological Service. The station was in charge of Lieutenant A. Baldit, who showed me, with justifiable pride and with inimitable courtesy, the equipment and organisation of his station; and in particular the arrangements for obtaining wind and the temperature in the upper air by "sound-ranging" a balloon carrying a small "Dines" instrument and the necessary explosive charges. That very afternoon an ascent had been made, the position of the signal balloon attached to the instrument had been determined by sound-ranging, a tender had been sent to obtain the record, but it had gone—one might guess that it had been taken by the finder (inspired with the conviction that "an enemy hath done this") for handing over to the proper authority and for transmission, through the usual channels, to its rightful destination.

And now Lieutenant Baldit has written an account of the work of a practical meteorologist, prefacing his book by a lucid description of his conception of the organisation, methods, aims, and inspiration of a meteorological service in times of peace in a country such as France or England. He is not a man of small views—he recognises that the meteorologist must first of all tackle the practical work of making observations and day-to-day forecasts—but he also contemplates the daily preparation of isobaric charts for the whole globe, a task "not more difficult nowadays than the construction of a chart for France in the days of Leverrier." In this I think he is inclined to err on the optimistic side. He visualises also the application of statistics in a systematic way to the problem of forecasting the weather, and deplores the small progress made in this direction: he is right; it is lamentable that no one to-day can give a precise answer to such a question as "What—according to the records of the last fifty years—is the probability of rain on an afternoon in July between the hours of 3 and 4 p.m.—what between the hours of 9 and 10 p.m.—in Paris—in London?" As M. Baldit indicates, the failure is due, in part at least, to the divorce between the forecaster and the climatologist in the normal organisation of a European Meteorological Service.

M. Baldit divides his book into three broad divisions, treating respectively of organisation and observation—of the variation of pressure and wind and related problems—and of weather forecasting.

He describes in some detail (1) a "regional" meteorological station illustrating his description by photographs and plans of the station at Châlons, and (2) a mobile meteorological station designed to move readily with a mobile squadron of aeroplanes and to keep the squadron informed more especially of the approach of thunderstorms, line-squalls, fog, and of low cloud approaching on a starlit night. In this section too he emphasises the importance, not only of good communication by telephone, telegraph, and wireless, but also of the personnel of a meteorological service who ought to have both the spirit and training of science and the physical activity indispensable to those who must themselves experience the weather in which they deal.

He describes the method of using captive balloons for meteorological observations, and shows how the invention of M. Rothé can be applied to give the wind at the level of the balloon (and at intermediate levels) to an observer on the ground by using the cable of the balloon for the transmission of electromagnetic waves from the recording instrument. He gives, too, an account of a method designed by Col. Saconney for obtaining the height of the upper surface of a cloud sheet. In this connection he remarks that a very clear indication of the passage of the balloon through the upper surface of the cloud is usually given by a sudden increase in the tension of the cable.

Another chapter deals with the use of the aeroplane for meteorological work: it may be remarked that the position of the instrument in the illustration on page 79 is not one which would commend itself to British meteorologists, although M. Baldit emphasises in the text the need for care in securing an exposure free from the temperature effects of the engine. It is certain that many of the earlier records of upper air temperature which were received from the French Service during the war were vitiated by faulty exposure of the instruments.

In the second part M. Baldit, after a clear explanation of the variation of pressure with height, devotes some pages to the theoretical relation between the wind and the gradient of pressure. It is apparent from a remark on page 177 that the French Meteorological Service did not make the use of this relation for obtaining the upper wind in overcast weather which the British Service consistently practised from 1916 onwards—partly, no doubt, on account of the admittedly greater divergence of the upper wind from the computed wind in the more hilly or mountainous region of the French front.

In the section on weather forecasting much attention is naturally devoted to the consideration of squalls, "éclaircies" (bright intervals or clearances), and thunderstorms. M. Baldit has given special attention to what he describes as "cold" thunderstorms. He indicates two types:

(1) Thunderstorms produced by the irregular advance of a cold mass of air, of which two advance "rivers" join and isolate a mass of warm damp air—the latter is then forced upwards and a thunderstorm results.

(2) Thunderstorms produced by an island of cold air (broken off from the main current) and acting as a miniature "polar current" along its advancing edge. In this connection a tentative deduction of W. H. Pick's is interesting, viz. that the probability of thunderstorms is much increased "if the simultaneous morning temperatures at inland stations show appreciable differences."

M. Baldit's opinion of Guilbert's rules is briefly that some do not give results which stand the test of experience and that others are quite useless, but that the fundamental rules of the abnormal and divergent winds, of the direction of translation of cyclonic centres and of the "dorsale" of high pressure, are of indisputable usefulness when they are properly applied.

M. Baldit's book is a new departure in text-books of meteorology—it breaks new ground—and it will prove of great interest and usefulness to meteorologists, especially to those who have not had the advantage of seeing "intensive" meteorology applied with all the resources, all the enthusiasm, all the responsibility of M. Baldit and his colleagues. E. GOLD

The Climates of the Continents. By W. G. Kendrew, M.A., Oxford (Clarendon Press), 1922. 8vo. Pp. xvi + 387. Illustrated. Price 21s. net.

The Climates of the Continents, as the title suggests, is a comprehensive volume. To write an adequate account of the climatology of so vast an area is a bold undertaking, and the book may be regarded as a pioneer work of its class. It is, in fact, an attempt to describe the climates of the world, for although the continents occupy less than one-third of the entire surface of the globe, their climatic conditions are so largely dependent upon the oceans that the study of these also is inseparably bound up with that of the land areas. That it is a pioneer work is indicated in the opening words of the preface where the author states that "this book aims at filling a gap." Treatises on meteorology and climatology abound, but none are extant in English treated from a purely geographical standpoint. The author freely acknowledges his indebtedness to many climatologists, both English and foreign, of whom the late Dr. J. von Hann must take pre-eminence. There are a few cases in which the latest information available does not seem to have been used; thus on page 18, in place of Buchan's charts of mean temperature in Africa which are taken from the "Challenger" Report and are based on few observations, the later charts published in the *Quarterly Journal* for 1919, p. 251, might perhaps have been used with advantage. The basis of the work is essentially statistical and the most recent data should have been utilised. In numerous instances, however, the information is the best available. To obtain climatological statistics extending over a long period is a task of great magnitude accomplished only by an innumerable band of observers, lesser lights in the world of meteorology, whose names can never be known. Without their labours a work like the present would have been impossible, and it has been left to Mr. Kendrew to unite their forces into a consolidated whole, an undertaking of no mean order.

The book is divided into seven parts, the first being introductory and the succeeding six dealing with each continent in turn. Africa is considered first, followed by Asia, Europe, North America, South America, and Australia.

In the introduction is a chapter on statistics as related to climate, but Mr. Kendrew has wisely refrained from overburdening his work or wearying his readers by introducing innumerable figures into the text. Each part is, however, followed by tables of mean monthly temperature and rainfall to which the reader may refer with advantage. The height of the station is given in each case, an essential addition to all meteorological tables. Extreme values are printed in special type, which enables the reader to abstract readily the main features portrayed.

The work is illustrated by a well-selected set of maps and diagrams. These form one of the main features of the book, and are not complicated by the introduction of irrelevant names and figures. They are boldly drawn, and at once concentrate the attention of the reader on the subject under consideration. The author is to be congratulated on the high standard of his work, and British meteorologists owe a debt of gratitude to him for bringing together such a vast amount of information within the compass of one volume.

H. W. B.

QUARTERLY JOURNAL
OF THE
ROYAL METEOROLOGICAL SOCIETY

VOL. XLIX.] APRIL 1923 [No. 206

AURORA AND ALLIED PHENOMENA.

By C. CHREE, Sc.D., LL.D., F.R.S., President.

[An Address delivered before the Royal Meteorological Society, January 17, 1923.]

§ 1. THE cause of aurora has been a fruitful subject for speculation. Modern theories invoke ions and other agents unknown to previous generations. If the theorists of to-day are on the right track, the theorists of fifty years ago had not the smallest chance of success. It is well to bear in mind the possibility that there are still unknown secrets of Nature, the discovery of which must precede the satisfactory explanation of aurora. Before dealing further with theories it is well to turn to the facts.

In one respect, at least, we know much more of aurora than we did twenty-five years ago. About that time the late Prof. Cleveland Abbe[1]—a Symons medallist—discussed the state of our knowledge as to the height of aurora. His historical researches disclosed an enormous number of estimates, arrived at in a variety of ways. After a comprehensive study of authorities, Abbe seemed almost a sceptic as to there being any such thing as a definite height for any auroral phenomenon. He thought it probable that aurora, even when possessed of an apparently definite form, had no definite locus in space.

It would, however, be erroneous to suppose that all the authorities quoted by Abbe had been equally unsuccessful. Here I shall refer to only one of them, that somewhat eccentric genius Henry Cavendish,[2] who estimated the height of an auroral arch seen in England in 1784. The data he employed were observations as to the altitude and position relative to the stars of the arch as viewed at three English stations. He considered that the height was not less than 52 nor much in excess of 71 miles. If we take an arithmetic mean of these two values, we get a height of nearly 100 kilometres, which agrees quite fairly with recent measurements of the height of the lower edge of aurora.

The obstacles to exact determination of auroral heights in Cavendish's time were chiefly two. To find the height of so lofty an object a long base is required. Aurora usually changes its position and shape somewhat rapidly, thus a close approach to simultaneity is necessary in the observations taken at the two ends of the base. This became possible only with the invention of the telephone. The second difficulty was in securing that the two observers employed identical points of the aurora. This difficulty was not overcome until Prof. Störmer[1] obtained satisfactory photographs of aurora with only a few seconds' exposure. Prof. Störmer has employed bases varying in length from 10 to more than 250 km. The observers at the two ends are connected by telephone, and the one in command decides exactly on what stars the cameras are to be pointed and when the photographs are to be taken. The stars appear in the photographs, as well as the aurora. The difference between the positions relative to the stars of selected auroral points on the photographs taken at the two ends of the base enables a calculation to be made of the height and other geographical co-ordinates of the auroral points.

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[1] *Terr. Mag., Washington, D.C.*, **3**, 1898, pp. 5, 53, 149.

[2] *The Scientific Papers of the Honble. Henry Cavendish*, vol. ii. p. 234.

Prof. Störmer[2] has introduced a number of devices for simplifying the calculations. Other Norwegian observers, including Messrs. Vegard[2] and Krogness,[2] have followed in his footsteps, and a large number of height measurements have now been made in Norway. The majority of the measurements refer to the lower edge, which is usually sharply defined. It appears at a somewhat variable level, but the most common heights are from 100 to 110 km. At the upper limit aurora often fades away into obscurity, and the height to which it can be traced in a photograph is largely a question of the sensitiveness of the plate. Heights exceeding 200 km. are not uncommon, and on March 22–23, 1920, when a bright aurora accompanied a great magnetic storm, Prof. Störmer measured several heights exceeding 600 km. and one of 750 km.

The possibility of aurora ever descending so low as to come between observers and distant mountains—as has been sometimes alleged—is naturally discountenanced by physicists who attribute aurora to the action of ions such as are encountered in the laboratory. No known ion could penetrate so far into the atmosphere. Those who regard our present knowledge of Nature's ways as possibly incomplete may prefer to keep an open mind. A similar remark applies to the question whether aurora is ever audible. That truthful observers have believed they heard it there can be but little doubt. A possibility to be borne in mind is that aurora may occasionally occur simultaneously with the form of electrical discharge known as St. Elmo's fire.

§ 2. *Geographical Distribution.*—Fritz's well-known scheme of lines of equal auroral frequency is still the most authoritative. His curves of equal frequency are not symmetrical, but the axis with respect to which they are most symmetrical departs considerably from the earth's axis of rotation. In Western Europe and in America lines of equal auroral frequency extend much farther south than in Eastern Europe and Asia. The frequency, for example, which Fritz assigns to Shetland is much above that of Asiatic stations of similar latitude. If, following the analogy of barometric pressure, we think of an auroral gradient steepest in the direction perpendicular to the lines of equal frequency, then we follow a direction of very steep gradient in travelling from the south of

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[1] *Videnskapsselskabets Skrifter Math. Nat. Kl.*, 1911, Nr. 17.

[2] *Kristiania Geofysiske Publikationer*, vol. 1, 1920–21.

England to the north of Scotland. According to Fritz, the annual frequency is only 5 in the English Channel but 100 in Shetland.

Some confirmation of the general accuracy of Fritz's figures may be derived from the auroral statistics which have appeared since 1917 in the Meteorological Office's *Geophysical Journal*. The nights when aurora was observed at some station or other in the British Isles numbered 64 in 1918 and 103 in 1919, the great majority of the observations being from the northern parts of the realm.

Satisfactory auroral statistics are particularly hard to come by. The sun has to be a considerable distance below the horizon before ordinary aurora is visible. In higher latitudes there is no possibility of seeing aurora near midsummer. Faint aurora is unlikely to be seen even in moonlight or when the sky is overcast. Within a comparatively narrow area like the British Isles the conditions for seeing aurora may be much more favourable in one year than another. Much may depend on the greater or less interest taken in the subject at a few of the more northern stations. This makes it difficult to compare different years.

§ 3. It has long been believed that aurora shows a general parallelism with sunspot development. It cannot be claimed that the parallelism in the waxing and waning of the two phenomena from year to year is striking. To put the matter to an exact test,[1] I considered separately two series of auroral observations each covering ten sunspot cycles. One series, due to Tromholt and Schroeter, was confined to Scandinavian data, the other, due to Lovering, was of a more general character. From each series two groups each of thirty years were selected. The one group contained the three years of largest sunspot frequency in each of the ten sunspot cycles, the other the three years of least sunspot frequency. The mean sunspot frequencies of the two groups in each case bore to one another the ratio 7 : 1. The auroral frequency from the sunspot maximum group of years bore to the frequency from the sunspot minimum group the ratio 16 : 10 for the Scandinavian data, and the ratio 15 : 10 for Lovering's data. The excess of auroras near sunspot maximum as compared with sunspot minimum is thus substantial.

The existence of a relationship between sunspots and terrestrial magnetism was recognised by the middle of the last century. It is of a twofold character. The relation least open to doubt is that between sunspot frequency and the range in the regular diurnal variation of the magnetic elements. The amplitude of the diurnal variation increases conspicuously with sunspot frequency, whether we employ all days or selected quiet days for the calculation of the inequality. Taking, for example, the period 1890 to 1900, we may regard large sunspot frequency as represented by the years 1892 to 1895, while small sunspot frequency is represented by 1890, 1899, and 1900. Employing the diurnal inequalities obtained at Kew from the records of the selected quiet days, five a month, we find the following mean results:

	Sunspot Frequency.	Declination Range.	Horizontal Force Range.
Sunspot maximum years . .	75·0	9′·37	32·9 γ
Sunspot minimum years . .	9·6	6′·71	20·5 γ

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[1] *Proc. Physic. Soc.*, **20**, 1906, p. 434, and *Phil. Mag.*, *London*, January 1907.

The second relationship, that between magnetic disturbance and sunspot frequency, is less uniformly manifested. The average year of many sunspots is more disturbed than the average year of few sunspots, but some years of large sunspot frequency have been less disturbed than other years having less sunspot development. For example, 1893, with a frequency of 84·9, was decidedly less disturbed than either 1892 or 1894, the sunspot frequencies of which were respectively 73·0 and 78·0. The absence of magnetic disturbance near sunspot minimum is perhaps more marked than the presence of disturbance near sunspot maximum.

§ 4. The annual variation in the frequency of aurora presents different features in different latitudes. In the southern parts of Scandinavia, the data given by Tromholt and Schroeter show two maxima of frequency near the equinoxes. Of the intervening minima, that at midsummer is the most pronounced. The data for the British Isles in the *Geophysical Journal* show the same phenomena. Thus, taking the years 1918 and 1919, we find that 50 per cent of the occurrences took place in the four equinoctial months March, April, September, and October, as against 37 per cent in the four winter months November to February, and 13 per cent in the four summer months May to August. In the northern part of Scandinavia the two maxima at the equinoxes disappear, a single maximum appearing at midwinter. Near midsummer no aurora is observed at all, this being a direct consequence of the continual daylight at that season.

The annual variation of magnetic disturbance in Britain agrees with that of aurora in having maxima near the equinoxes. Taking the 726 magnetic storms recorded at Greenwich between 1848 and 1903 as given in Maunder's[1] lists, 42·3 per cent occurred in the four equinoctial months, as compared with 32·1 per cent in the winter, and 25·6 per cent in the summer months. Magnetic data for high latitudes are too meagre for the deduction of general laws. In the Antarctic, judging by the results of recent expeditions, the maxima of disturbance near the equinoxes vanish and are replaced by a single maximum at the Antarctic *midsummer*.

§ 5. Considerable divergence of opinion prevails as to the intimacy of the connection between simultaneous auroral and magnetic phenomena. Some light is thrown on this point by the data in the *Geophysical Journal*. A monthly table includes all nights when aurora has been seen anywhere in the British Isles, with, for comparison, the magnetic "characters" awarded at Eskdalemuir and Kew to the two days respectively beginning and ending on the night in question. These magnetic characters are 0 ≡ quiet, 1 ≡ moderately disturbed, and 2 ≡ highly disturbed. Assigning to the night the mean of the magnetic characters assigned at Kew to the coterminous days, the mean characters for auroral and non-auroral nights were respectively 1·34 and 0·62 in 1918, while in 1919 they were respectively 1·12 and 0·52. The excess of magnetic disturbance on the nights of aurora was thus very large. Again, in the Antarctic in 1911, aurora was observed by members of the Scott expedition[2] both at Cape Evans—the headquarters where the magnetograph was in operation—and at Cape Adare. The auroras observed at each station being arranged in four classes, I. ≡ very bright, II. ≡ bright, III. ≡ faint, and IV. ≡ very faint, the mean magnetic characters for the several groups of days were as follows:

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[1] *Mon. Not. R. Astro. Soc.*, **65**, 1905, pp. 2 *and* 538.

[2] *British* (*Terra Nova*) *Antarctic Expedition*, 1910–1913. *Terrestrial Magnetism*, pp. 406, 409 ; also *Observations on the Aurora* (London, 1921).

Auroral Group.	I.	II.	III.	IV.
Observations at Cape Evans . .	1·28	1·06	0·93	0·66
Observations at Cape Adare . .	1·44	1·23	1·02	0·84

The character figure associated with very faint aurora at Cape Evans is well below the mean from all days. In these high latitudes, it should also be remarked, days absolutely free from magnetic disturbance are rarely, if ever, encountered. The natural conclusion would seem to be that it is a question not of the existence or non-existence of aurora and magnetic disturbance, but simply of greater or less intensity. Aurora, to be visible to the eye, must have a certain intensity, varying, of course, with the amount of other illumination present at the time. What is known of the so-called auroral line points to the same conclusion. Gases when heated, or electrically excited show a line spectrum, the lines being characteristic of the gas. The auroral spectrum shows in reality a number of lines, but one of these in the green—the source of which is still a matter of speculation—is so specially characteristic as to be generally known as *the* auroral line. The fact that this line was always or nearly always recognisable in a spectroscope in Finland—whether aurora was visible or not—was asserted before the end of last century by Prof. Lemstrom of Helsingfors. This conclusion was not, I think, generally accepted at the time; but in recent years Dr. Slipher announced that the line was regularly visible in America, and its presence under normal conditions in England has been demonstrated by the present Lord Rayleigh.

§ 6. This brings us to auroral theory. As soon as any new discovery is made in physics in the laboratory it is usual for some one—usually several people—to suggest its application to explain some phenomenon of Nature. But something more is wanted to make such obvious suggestions of real value. The late Prof. Kr. Birkeland of Christiania was, I think, really the first man whose speculations on the cause of aurora merit attention. He believed the sun, probably sunspot areas, to be the source of cathode rays which penetrated the earth's atmosphere and became visible as aurora. Prof. Birkeland's colleague Prof. Störmer, who is an accomplished mathematician, attacked the problem mathematically. To reach any numerical results, he had to simplify the problem in a variety of ways. He assumed, for instance, that the interaction of the rays emanating from the sun was negligible. He also assumed the earth to be a uniformly magnetised sphere. It is known, of course, that this is not strictly true; but the analysis introduced by Gauss, and since applied by various mathematicians, shows that to a rough first approximation the earth may be regarded as uniformly magnetised, the magnetic axis being, however, inclined to the axis of rotation. The estimated position of the north end of this axis is roughly 78°·5 N., 70° W. The rays, whatever be their sign, tend to describe spirals round the earth's lines of magnetic force. They are thus, as it were, attracted towards the ends of the magnetic axis. It results from Prof. Störmer's[1] calculations that the extreme angular distance Ω from the magnetic axis at which aurora can occur is given by

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[1] *Terr. Mag. Washington, D.C.*, **22**, 1917, pp. 23-34 and 97-112.

$$\sin\Omega = \sqrt{2D/c},$$

where D is the distance of the aurora from the earth's centre and

$$c \equiv \sqrt{M/F\rho},$$

M being the earth's magnetic moment, F the strength of the earth's field, and ρ the radius of curvature of the ray's orbit at a point where the tangent is normal to the magnetic force. For the value of M, Prof. Störmer takes 83×10^{24} C.G.S. units.

For ordinary cathode rays $F\rho$ is of the order 100 to 500, while for α rays it is of the order 300,000 to 400,000. For small values of $F\rho$ we have large values of c and small values of Ω. For cathode rays Ω varies from 2° to 4°, for β rays from 4° to 6°, and for α rays from 16° to 19°.

The small size of Ω is a serious difficulty. It appears much less serious for α rays, which carry a positive charge, than for β or cathode rays, and for a time the α-ray theory appeared to be favoured by Störmer and strongly advocated by Vegard. As long as he lived, Birkeland maintained the cathode ray theory, but he seemed forced to the conclusion that the sun's cathode rays must be of a very different type from any yet produced in the laboratory. He attributed to these unknown rays a velocity only just short of that of light. It would be interesting to know what bearing Einstein's theory may have on this hypothesis.

Even with α rays Ω is much too small, and auxiliary hypotheses have been invoked. Prof. Störmer has suggested that magnetic storms and aurora in low latitudes may be explained by an attraction exerted on the rays by an invisible Saturn ring of ions of one sign describing orbits about the earth in a plane perpendicular to the magnetic axis. This is, however, a pure speculation. No satisfactory explanation has been given of how such a ring could come into existence, or how it could persist for hours if created.

Recent investigations into the luminosity of aurora have disclosed serious difficulties in the way of the α-ray hypothesis, and Vegard—who used to be its most ardent advocate—seems to have reverted to the β or cathode ray hypothesis.

The calculations made by Störmer[1] and Vegard,[2] or by Vegard[3] and Krogness, as to what happens to the auroral ray when it gets near the earth are largely dependent on their assumptions as to the constitution of the upper atmosphere. The different gases of the atmosphere are supposed to remain mixed only up to comparatively low levels. At high levels in the stratosphere they are supposed to separate, so that the proportion of the lighter constituents continually increases with the altitude. At heights exceeding 120 km. the pressure is supposed to be largely dependent on helium and hydrogen. These gases are so rare at the earth's surface that the proportion they form of the atmosphere is open to doubt. If there is anything in the conclusions recently drawn by Lindemann and Dobson[4] as to the comparatively high temperature of the stratosphere, the calculations recently made by Störmer and Vegard independently would require revision.

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[1] *Kristiania, Geofysiske Publikationer*, vol. **1**, 1920–21, No. 5, etc.

[2] *Phil. Mag.*, *London*, **42** (1921), p. 47.

[3] *Kristiania, Geofysiske Publikationer*, vol. **1**, 1920–21, No. 1, etc.

[4] *Proc. R. Soc.*, **102** (ser. A), 1923, p. 411.

§ 7. Finally, we may consider briefly what light is thrown on the subject by the phenomena of terrestrial magnetism. That magnetic phenomena on the earth are largely influenced by a discharge of some kind from the sun seems practically certain. In addition to the 11-year period in the regular diurnal variation, we have an unmistakable 27-day interval in magnetic disturbance, for which no explanation has been suggested other than the solar rotation. Magnetic disturbance is clearly dependent on electrical currents of some kind in the upper atmosphere. For an electrical current two things are wanted: an electromotive force, which from an analogy based on economics we may regard as *capital*, and carriers of positive and negative charges, which we may regard as *labour*. If we consider the magnetic diurnal inequality, the period is obviously determined by the earth's rotation. If we suppose the electromotive forces to be determined by that rotation, then at any instant we may divide the earth's atmosphere into a part A in which the electromotive forces produce electric currents which deflect the compass needle at, say, Kew to the west, and a part B in which the electric currents have an opposite tendency. An additional supply of free ions to region A causes increased westerly declination, a supply to region B has the opposite effect. If we compare the diurnal inequalities of declination in years of many and years of few sunspots, we find little difference in the type but a large difference in the amplitude. The solar radiation endures throughout the same hours of the day in years of many and few sunspots. The discharges received from the sun in two years would naturally have the same law of distribution throughout the 24 hours, only the supply would be uniformly greater at sunspot maximum. Thus at sunspot maximum we should expect no difference in the distribution of current from that prevailing at sunspot minimum, but the current would be uniformly enhanced everywhere.

In the Antarctic a parallel phenomenon can be recognised even within the compass of a few months. If we take the five magnetically quietest and the five most disturbed days of each month, and take a sufficient number of months to get reasonably smooth results, the diurnal inequalities which we derive from the two sets of days differ largely in amplitude but little in type. Some of the phenomena, however, are less simple. Diurnal inequalities of declination at Kew derived respectively from quiet and disturbed days differ decidedly in type. Taking the year as a whole, the *principal* minimum (easterly extreme) appears about 7 a.m. in quiet days, but from 8 p.m. to 11 p.m. in disturbed days. This might, however, be explained by variability in the supply of "labour" throughout the 24 hours. Disturbance at Kew has a large diurnal variation, being much more frequent from 8 to 11 p.m. than it is near 7 a.m. Thus a larger supply of ions at the former hour would be natural.

The difference between the phenomena exhibited by the vertical and horizontal components of force presents greater difficulty. On days of very large disturbance vertical force is as much disturbed as the horizontal components. But on days of moderate disturbance in the horizontal components, the vertical component at Kew and other stations in mean and low latitudes often shows very little disturbance. This would seem difficult to explain on the "labour" hypothesis, unless the electric current systems on which the vertical force variation depends are at a lower level in ordinary latitudes than the others, and solar electric radiation fails to penetrate to these levels except on special occasions.

§ 8. Phenomena so complicated as aurora and magnetic disturbance are hardly likely to be fully explained by any simple hypothesis. But it seems abundantly clear that high terrestrial latitudes provide in much fuller measure than low latitudes the phenomena the explanation of which is desired. The installation in Shetland of a magnetic observatory is thus an important event. Assuming an ordinary amount of clear weather in winter, the station should be very favourably situated for auroral observations. There are many directions which auroral work may take. For the comparative study of the incidence of aurora at different hours, or in different months, or in different years, systematic nightly observations are necessary. During nights of aurora a continuous outlook is desirable, so that the sequence of events and the exact times of occurrence of outstanding phenomena may be noted for subsequent comparison with the magnetic curves. Observations of auroral heights after the method of Störmer are of fundamental importance, and with them should go the study of the spectrum. If the spectrum from long auroral rays could be studied at different levels in the atmosphere, its constitution might be determined at different heights, just as the geological structure of the earth at different depths may be derived from the core of a boring. The auroral line would naturally form a special subject of research. A well-equipped laboratory for the study of artificially produced spectra would obviously be a desirable auxiliary. The relation of aurora to earth currents is important. The influence, if any, of aurora on wireless calls for investigation.

The staff and equipment necessary for the prosecution of research on all the above lines are obviously more than the State can be expected to provide in these impoverished times. It is thus to be hoped that some wealthy Maecenas will recognise in auroral investigation a subject worthy of his firm support.

The address, as delivered, was illustrated by a number of lantern slides. Some of these were photographs of aurora taken from the two ends of a base, which were kindly supplied by Prof. Störmer.

ON THE GROWTH AND DECAY OF VORTICAL SYSTEMS.

(SECOND MEMOIR ON VORTICAL PHENOMENA.)

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[Received June 15, 1922—Read February 21, 1923.]

[The Editing Committee desires to record its acknowledgments to Captain D. Brunt and Sir Napier Shaw for supervising the passage of the original type-script of this paper through the press in the absence of the author. They have made such verbal corrections and minor alterations as seemed necessary, and have added a few notes.]

SUMMARY.

THE paper treats of the following ideas or propositions.

1. Vortices have individuality.
2. Vortical systems exhibit "animate" growth[1] by taking in various embodiments of energy which are favourable for their growth, and by rejecting those which are unfavourable.
3. Selective ability (power of discrimination) is one of the essential attributes for animate growth.
4. Animate growth sets in and is maintained under unstable conditions, so that the phenomenon is controlled by a condition of "no uniformity."
5. Equations and curves for animate growth of vortical systems have a form very similar to those for vital growth.
6. The law of decay is the expression of a principle of tendency towards uniformity, with which many important laws of physics may be ranged, such as the second law of thermodynamics, Ohm's law of the electric current, etc.
7. The law of animate growth is the law of developing inequality. This is exemplified by the law of gravitation, etc.
8. Cyclones and sunspots exhibit the characters of animate growth.
9. Over the earth's surface we can observe various kinds of vortical configurations of various dimensions, *e.g.* the mountain range joining the Alps to the Himalaya may be classed as a chain of vortical formation.
10. Special attention is asked for the analogous properties between "animate" and vital growth.

The present paper is only a quite young sprout from a small seed of

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[1] ANIMATE GROWTH.—The author uses this term in a special sense which is explained in § 4. He runs some risk of being misunderstood fundamentally if the reader is led away by the etymological associations of the word, which do not apply in this case. The author distinguishes between "animate" growth and "vital" growth. The use of the term *animate* derives from the expression "inanimate material agency" used by Lord Kelvin to describe the limitation imposed by the second law of thermodynamics. In the sense used by the author, growth, which by some automatic adjustment of conditions between the growing body and its environment ostensibly evades the limitations of the second law, is for that reason entitled to be called "animate," although the condition of adjustment lies in physical structure which is purely material and lifeless, not in the exercise of function or volition which he calls "vital."

THE PRINCIPLE OF EQUALITY OR OF SYMMETRY OR OF UNIFORMITY.—The general principle upon which the author relies as analogous to the second law of thermodynamics is variously worded in the paper according as the contrast is between equality and inequality of magnitudes, symmetry or asymmetry of structure, or between uniformity or equipartition and diversity.

eastern idea sown in the soil of western science. It is still weak and liable to change. The above résumé is, in one respect, the mere expression of a wish for solidification in the future.

As a concluding remark in the above sense we can probably say that *all events, phenomena, or activity are originated only from diversity, without which there is no growth or decay.*

I. Introduction.

§ 1. *Definition.*—Under "vortical motion" we understand here just what is defined in hydrodynamics. Vortex has two meanings. In the first meaning it is the contents of a closed surface called a vortex tube which is generated by vortex lines along any closed curve in the field.[1] A vortex in the second meaning is the total vortical field making a common revolution round an axis.[2] For the sake of convenience we shall call the vortex of the first meaning by its original name vortex filament. We shall also use the concept vorticity, of which the three components are—

$$\xi = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}, \quad \eta = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}, \quad \zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y},$$

where the symbols have the ordinary meaning. In this paper we shall confine ourselves to the use of vortex in the second meaning only, with or without accompanying radial as well as axial motion, so that the vortex can contain any number of vortex filaments, among which the axial one is the most important. Whenever we need to distinguish this from the others, we shall call it the axial or central filament. Every vortex has its own individuality; we can count vortices when there are many. A vortical filament is a mere abstraction, and is a property of every part of a fluid medium irrespective of discontinuity; we can measure it with some premised unit, but it cannot be counted, because it has no genuine individuality. It is important to emphasize the individuality of a vortex, which will be the object of some interest in a later paragraph. The word whirl will be used sometimes in place of vortex.

§ 2. *Actual Vortices.*—There are many kinds of vortical motions of fluid. We can divide them into two main classes from the point of view of energy. Some vortices have their sources of energy at their centres, or cores, or axial parts, *e.g.* water or air vortices produced by rotating a solid piece in water. Many vortices in nature, however, have the sources of their energy in the moving medium; for example, vortices at the boundary of two opposing water currents.

Some of the characteristic properties of the vortex are common to both kinds, for example, the tendency to symmetry. There are, however, many properties characteristic of one or other of them, *e.g.* the modes of their growth, which are quite different. We shall observe mainly the growth and decay of these vortices in the following pages.

§ 3. *Growth.*—Before proceeding further we must define or at least form some conception of "growth." Growth is a common phenomenon in living things, and in ordinary cases it means the increase in volume or in mass. Meteorologists use words like "the life-history of a cyclone," and they are accustomed to observe the growth and decay of cyclones and anticyclones. In that connection the word "growth" is used mostly for the increase in the cyclonic intensity. We speak of decay, if a cyclone decrease its barometric depth, though increasing in its area. Thus in a tentative way we shall define the growth of a vortex as "the increase of the total kinetic energy pertaining to that motion." Such growth can be attained in some cases by the increase of mass when the energy per unit mass remains constant. In other cases the growth will take place by the increase of the energy-density per volume or mass if the total volume or the total mass remain constant. Actually both changes can take place at the same time. A question will then arise as to what is the volume or mass of a vortex. When a single vortex exists in water in one vessel the answer is very simple. But when there are many vortices in a wide field of mass of some fluid, it is very difficult to draw boundaries between them. In order to get over the difficulty we can adopt some conventions, for example, choose a limit of sensible vorticity and draw the surface of equal vorticity according to that limiting value. Then we can compare the mass or volume contained within that surface for successive moments to see if it is increasing or decreasing.

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[1] See Lamb, *Hydrodynamics*, p. 194, 4th ed.

[2] *Loc. cit.* p. 214, 4th ed. Here vortex is not explicitly defined, but the meaning is understood. Thus the vortex in the second meaning is a special kind of that of the first meaning.

§ 4. *Vital, animate, and inanimate Growths.*—For the present we must confine ourselves to the domain of physical science, excluding from our consideration the growth of living creatures which we shall call vital growth. Perhaps we can use the words *animate and inanimate growth* for growth in the physical world. Inanimate growth means mere increase, for example, the mass of water in a rain-gauge when it is raining. Such increase is only caused by means of an external agency, and needs no special study as a phenomenon of growth.

Another example of the same kind of growth is the increase of heat quantity in a cold body by contact with a hot body. Then the temperature can be raised so far as that of the hot body but no further. That means that the average molecular motion cannot be more intense than that in the heat source, so that this is also inanimate growth of heat energy.

As suggested by Maxwell, heat can be accumulated by an agency such as "Maxwell's Demon." The late Lord Kelvin called it "animated agency." If then the growth should occur in such a way that its intensity exceeds the intensity of the energy source or the surroundings *by its own action* we may call it *animate growth.* For example, if one molecule make collisions only with those molecules which have higher velocity than itself, then its velocity can get greater and greater. Then the energy of this molecule shows animate growth. It is clear from the second law of thermodynamics, or better to say from the law of probability, that such things cannot happen in ordinary cases. If such a molecule can get a velocity greater than that of any other molecules existing in the same field, not by a mere chance nor by means of any external agencies but *by its own action*, then the growth can be thought much more animate, and perhaps we can use the words "animate growth of the second order," for the growth beyond the existing maximum, the first order being the mode previously mentioned, *i.e.* growth beyond the average but not beyond the maximum.

Not only for one molecule but also for any assemblage of molecules, with respect to their average condition, or for any continuous system, we can use the same words "animate growth" in the sense described above. If a vortex by its own action can increase its intensity to a higher degree than ever existed in the surrounding medium, taking energy from the latter, then we can regard it as having animate growth.

II. Observation of Facts.

§ 5. *Growth of the Vortex.*—The vortex has two modes of growth, animate and inanimate. Inanimate growth can be very easily observed. For example: if we dip a rotating piece of solid material into still standing water then we can recognise the growth of a vortex column starting from the rotating piece and deriving its energy from the rotating body. Animate growth of a vortex can occur either when two vortices of the same sense of rotation approach together and unite into one, or one comparatively large vortex absorbs smaller vortices having the same sense of rotation.

On Plate VII. we can see how vortices at the boundary of salt and fresh water change their positions. In the first figure there are three main vortices (*a*), (*b*), (*c*), which have anti-clockwise rotation, and two rather faint vortices (*d*), (*e*) of clockwise rotation.

Two vortices with the same sense of rotation have a tendency to approach each other when they are within the limit of their mutual action, and two with different senses of rotation have a tendency to separate one from the other.[1] Thus the second figure shows (*b*) and (*c*) to have approached nearer and amalgamated and made up a fair vortex, while (*d*) and (*e*) have moved away from (*b*) and (*c*). Perhaps there was some other action by which (*a*) and (*b*) could not unite, but (*a*) advanced farther in the direction of the motion of the salt water current and became circular, following the law of the tendency to symmetry.[2]

On Plate VIII. we can see one section of the periodic changes which took place at the boundary of salt and fresh water currents. In this plate AB and CD are the boundaries of the currents, and along AB anti-clockwise, along CD clockwise vortices are produced. Arrows show the direction and intensity of currents.

In No. 1 (Pl. VIII.) we can see a series of small vortices along AB. There occurs, so to speak, the struggle for existence; one or two vortices get superior power, the remaining ones contribute to them, and they naturally increase their intensity by swallowing others. One vortex marked (*a*) swallowed nearly all the neighbouring vortices and in No. 2 has attained its most conspicuous phase. Two small vortices are seen still making haste towards the right to reach the final goal (*a*). On the left-hand side a small vortex marked (*b*) is now in the phase of increasing strength. Three vortices, two from the left, one from the right, are converging to (*b*). In No. 3 one vortex at the left top end is still growing, while one in the right top part has passed its age of maximum strength, and three secondaries are produced, *i.e.* the centre of activity was divided into four which are making common revolution along a

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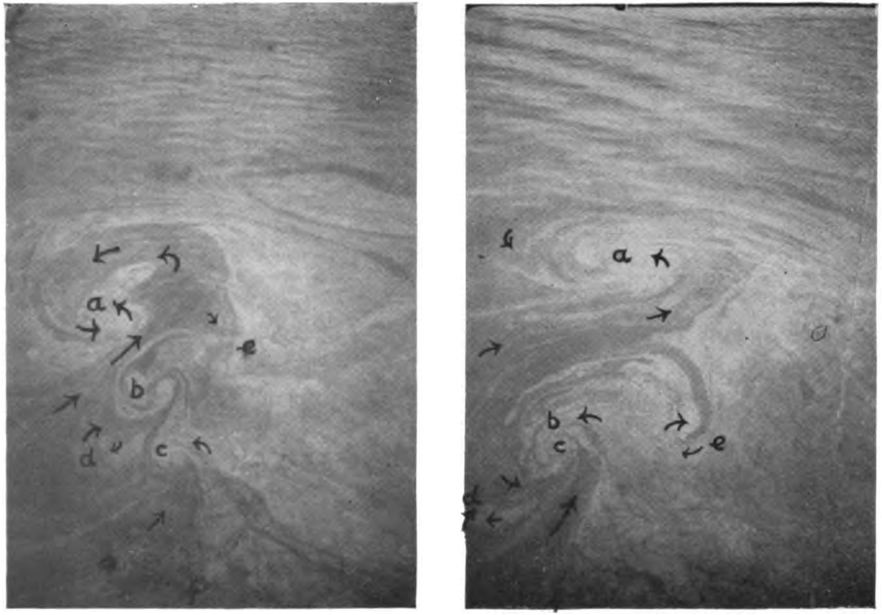
[1] This property is explained in later paragraphs.

[2] Fujiwhara, S., "The natural tendency towards symmetry, etc.," *Q.J.R. Met. Soc.*, **47**, 1921, pp. 287-293.



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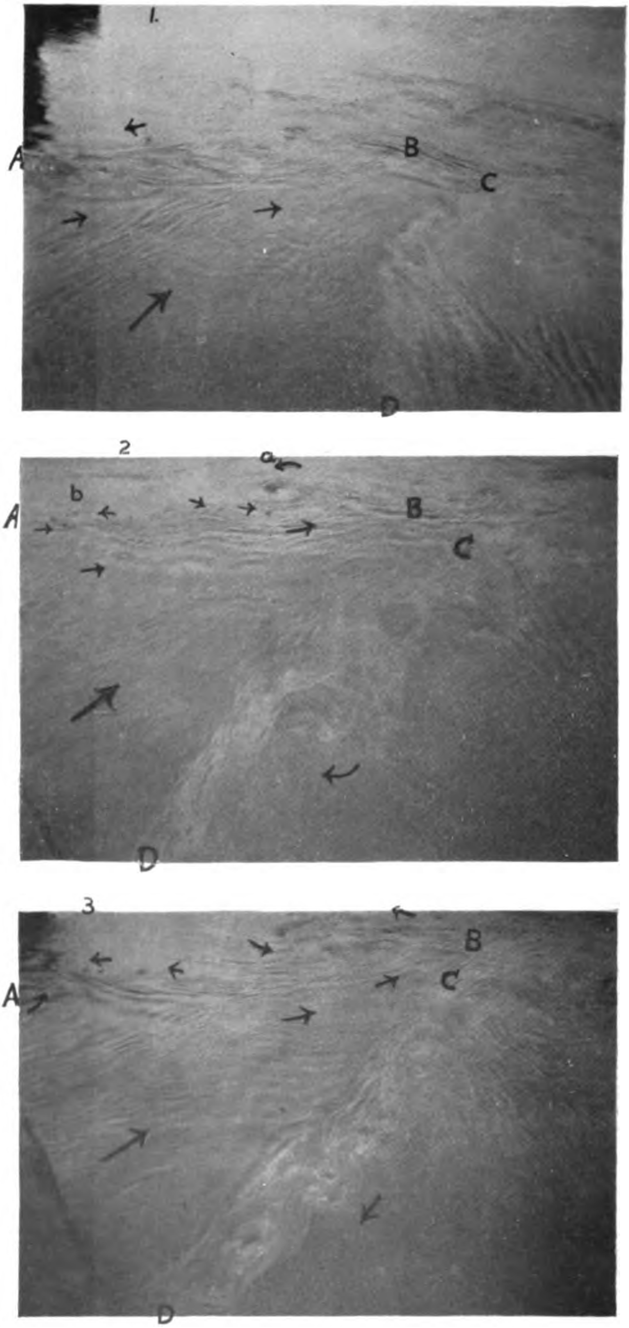
2

Growth of a vortex by the amalgamation of two vortices.

1. Vortices *a*, *b*, and *c* have the same sense of rotation, while *d* and *e* have the opposite.
2. Vortex *a* has become more symmetrical ; *b* and *c* have amalgamated and increased ; *d* and *e* have removed from *b* and *c*.



Growth of a vortex by absorption of smaller vortices of the same sense of rotation.

1. Many small vortices of anti-clockwise rotation along a surface of discontinuity **A B.**
2. Converging of small vortices to a big one.
3. Similar to No. 2 in the left top part; exhibiting decay by division and divergence in the right top part.

circle while the centre of the circle is comparatively calm. The area of the vortex is enlarged in spite of its decreasing intensity. The next phase is the decay of the vortex (not shown in the figure), and then again birth of many small vortices in one chain, and nearly the same process described above is repeated, though the periodicity is not so regular as in wave motion.

§ 6. *The experimental Proof of animate Growth of a Vortex.*—I have used an apparatus consisting of a water tank with vertical spindles and mechanism to give rotation to them. The mass of water has a dimension of 36 cm. square and 10 cm. deep. The spindles can make about twenty revolutions in one second, the speed depending a little on the state of vortical motion of the water. Water vortices can be produced by driving the spindles. The vortical state in the water can easily be observed by means of minute flakes of white and charred paper mixed in water, since the bottom and the sides of the tank are painted half white and half dark. With this apparatus the following events may be observed:

(1) So long as a spindle is rotating, one vortex having the spindle as its axis is maintained in position.

(2) Along the axis an upward or downward component of motion is produced according to the following three actions:

(i.) The centrifugal force of the rotational motion.
(ii.) Boundary conditions; in the present case a solid bottom below and a free surface above.
(iii.) Kinematical state of the water.

By (i.) diverging vortical motion is produced at the level of the spinning metal piece attached to the end of the spindle. By (ii.) it is easier for water to ascend than to descend, so that at the centre of the vortex a tendency for ascent is more successful than one for descent. By (iii.) converging motion or diverging motion is sometimes accelerated and sometimes retarded. So that if we put the rotating piece near the surface, we can nearly always get an ascending current at the centre. But if we put it in a middle or lower position the actions (i.) and (ii.) cancel each other, and we can have sometimes ascending and sometimes descending currents at the centre according to action (iii.).

(3) When one central vortex exists, secondaries can be easily made by moving a flat plate of metal, such as a steel scale, in the upper part of the water from the surface to a depth of some 3 cm., the plane of the scale being kept vertical.[1] Two vortices with vertical axes develop just behind the plate along each of its edges, having different senses of rotation. When the central vortex, C, is in the converging phase in its upper part these secondaries, S, D, show the following phenomena (see Fig. 1).

(i.) Behaviour of a secondary indicated by S in Fig. 1 having the same sense of rotation as the central vortex.

(*a*) When S is situated nearer to the centre than the other one, D, it moves directly to the centre and unites with the central one, C. Its path is not much curved.

(*b*) When S is situated farther from the centre than D, it first moves very slowly, but when D has moved away to some distance, S gets velocity and many times but not always—it depends on the intensity and distance from the centre—it crosses directly the revolving current of the main motion and approaches the centre, gaining strength meanwhile. When it comes near to the centre it revolves round the centre and at last unites with the central vortex.

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[1] When the verticality is not good, a horizontal vortex filament connecting these two becomes powerful and it destroys the success of the experiment.

(*c*) When S is too far distant from the centre, it does not go to the centre, but is carried to some distance by the general current and gradually dies away.

(ii.) Behaviour of a secondary with different sense of rotation, symbol D.

(*a*) When D is at the same distance or farther from the centre than S, it moves away taking an open parabolic path.

(*b*) When it is nearer to the centre than S, it goes round the centre, but does not unite, and moves away taking an ordinary parabolic path. Just at the moment when it passes the vertex of its path, the nearest point to the centre, it affects the central vortex. Two cases may happen. In one case the free end of the central filament deviates a little to the opposite side from D. As D moves away, the free end makes revolution round the spindle axis and at last recovers its central position. In the other cases (see Fig. 1, *d*) a new vortex, symbol N, is induced on the opposite side of the centre from D. N has the same sense of rotation as the central vortex, and as D moves away sometimes N is carried away with D, but in many cases it makes revolution round the centre and unites with the central vortex.

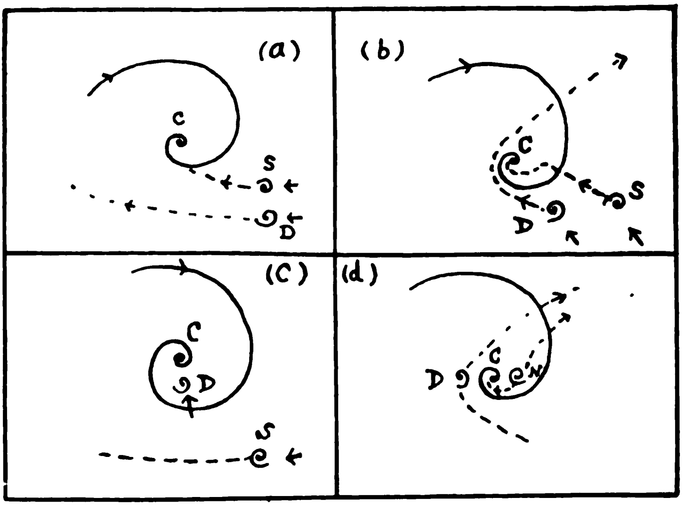

FIG. 1.—Behaviour of secondaries.

(*c*) When it is too near to the centre and projected towards the centre, it approaches a little to the centre but is very quickly destroyed.

(4) Whenever secondaries of the same sense unite with the central vortex, the latter gets strength; whenever the destruction of secondaries of a different sense occurs near the centre, the central vortex loses strength. We can see it by the increase or decrease of the depth of the central hollow.

From these observations we can conclude that:

(i.) Between two vortices with the same sense of rotation there is a tendency to approach, and between those having different senses of rotation there is a tendency to move away one from the other. These tendencies, however, are sometimes conquered by other actions.

(ii.) When the amalgamation of two vortices of the same sense of rotation takes place, the vortical motion gets new strength, and when two of different senses of rotation are forced to approach each other, the result is the destruction of the weaker one and decrease of strength of the stronger one.

III. General Explanation of Growth and Decay.

§ 7. *Mechanism of Amalgamation of two Vortices.*—In their true nature, the amalgamation of two vortices and the absorption of one vortex by the other are quite the same things. We shall consider the case of amalgamation of two, one big and one small.

So far as has been taught by ordinary hydrodynamics, two vortical filaments with the same sense of rotation repel each other and those with opposite rotation have attraction between them.[1] Such a result was deduced mathematically under the assumption of an ideal fluid.

Our actual observation apparently proves the existence in water of the opposite as a matter of fact. What is the reason of this contradiction? Is it due to the absence of friction in ideal fluid? The mathematical vortices are supposed to be made up of ideal fluid, but our actual ones always are associated with friction. It is quite obvious that those forces of attraction or repulsion which are proved mathematically must exist also in a frictional field, though they are not the only forces of importance. We must not imagine that approach is always accompanied by attraction and separation by repulsion. For example, a comet moves away from the sun after it has passed its perihelion, although attraction is exerted between them. When the kinematical effect is powerful enough the effect of repulsion may be neglected. In an ordinary vertical vortex in flowing water, the motion consists of pure vortical, axial, and radial motion. The axial motion near the free surface is downward as long as the vortex is young. The radial motion, as a consequence, is inward. As it becomes old the latter changes to weak outward motion. When a comparatively small vortex, say A, comes into the field of a large young vortex B, of the same sense of rotation, A gets the general motion of B. Meanwhile, the rotational motion of A superposed upon that of B, results in A passing obliquely across the stream lines of B with a motion similar to rolling;[2] the lateral and radial resultant motions with respect to the centre of B are intensified, and when A is quite near the centre of B the two centres make common revolution with each other and at last amalgamate into one, by which the velocity is increased over that of either of A or B. In Plate IX., No. 1 we can see two vortices just amalgamating at the left edge of the picture. When A and

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[1] See Lamb, *Hydrodynamics*, p. 216, 4th ed., only applicable to rectilinear vortices; also see V. Bjerknes, *Die Kraftfelder*, p. 148, Braunschweig, 1909.

[2] Dr. H. Jeffreys suggested to me that between two vortices of the same sense of rotation the variation of velocity is very great, and when the fluid is viscous the velocity at this part is destroyed very quickly and rolling motion must be the result.

B have different senses of rotation, just the opposite action occurs and the two move away from each other.

When B is in the same sense of rotation as A, but is so old that the radial motion is outwards, then A will keep making revolution along a circular path within B. On such an occasion one or more vortical centres will be induced on the circular path, which enlarges itself gradually, and the system breaks up into a small number of separate vortices.

§ 8. *What is the Essential Action of Animate Growth?*—Why is the growth of the vortex explained above an animate one? As may be seen with "Maxwell's Demon" or the single molecule described in § 4, the virtue by which they can accumulate energy is their ability for *selection.* "Maxwell's Demon" will select the molecules which have higher velocities and let them pass the gate so that energy is accumulated inside. The molecule described above also selects molecules which have higher velocities than itself and makes collision and increases its velocity. Now vortices have the ability to distinguish the sense of the rotation of the others near by. They join with those of the same sense and reject the others. Of course the vortex has no mind as ordinarily understood, but the above action may be looked upon as the most primitive type of selective ability. Thus a vortex can accumulate energy and can attain higher intensity than previously existed or is existing in its neighbourhood. There is another example of simpler selection, *i.e.* the phenomena of mechanical or electromagnetical resonance. By resonance the energy can be absorbed by a resonator selectively from the field of agitation, and its intensity can reach far beyond the average. So that this is also a kind of animate growth. But the animate nature is less striking with this than with a vortex.

The vortex can also take the energy of the other forms, *e.g.* that of the wave motion.[1] In Plate IX., No. 2 we can see a vortex which is taking in two wave crests. The vertical vortex can also take in a long horizontal vortex. In so far as the vortex takes more energy in and gets more strength, its power of taking in increases and it becomes more able to take in those far distant which were formerly beyond the range of its power. This is an essential property of animate growth, which *thus certainly is an unstable phenomenon; a system with animate growth has no constancy; it is always changing.*

After the consumable energy in the field is exhausted, the vortex loses energy by the action of the new-born secondaries and viscosity and declines gradually to death. We shall treat the problem mathematically in later paragraphs.

§ 9. *Looking back to the Principle of Equality.*—In order to lay stress on the importance of the animate character of the vortex, we must also emphasize *the universal prevalence of the law of decay*, that is to say, *the principle of a tendency towards uniform distribution, which we shall call the principle of uniformity or equality,* from which the principle of tendency towards symmetry is derived. There are many other laws which belong to that great principle: for example, the second law of thermodynamics, Boltzmann's principle of the equipartition of energy, Lenz's law of electromagnetism, law of diffusion, etc.

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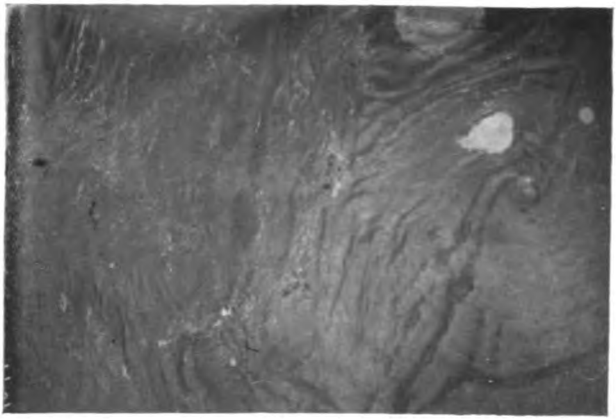
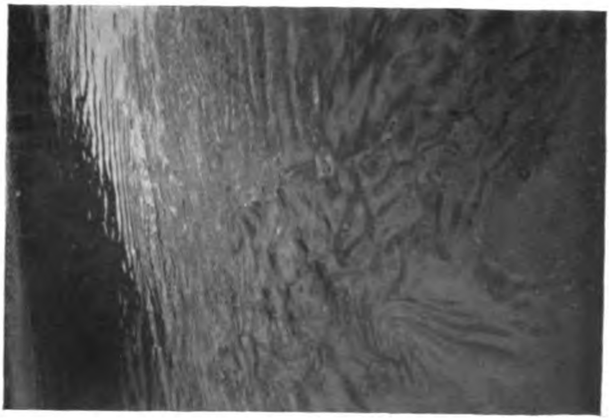
[1] Potential energy tends to kinetic energy. A vortex can accumulate various kinds of kinetic energy, so that it takes in, of course, the energy originated in the potential form.



1. Two vortices just amalgamating.



2. Absorption of wave motion by a vortex.

The second law of thermodynamics announces the tendency of entropy to the maximum, which in plain language means the tendency towards the equality of temperature when there is no hindrance to it. The principle of the equipartition of energy needs no explanation, because it is explicitly the law of tending towards uniformity. Lenz's law is that the effect induced by a cause acts to equilibrate the latter, which means the dissipation of the impressed potential of the cause. Ohm's law also treats the same principle, because the electric current always runs in such a way as to lower the existing potential difference, the higher the potential difference the stronger the current, that is to say, the further from equality the stronger the tendency toward it. We can find any number of examples supporting the principle in nearly all branches of physical science so far as the dissipation of the available energy is concerned.

We have the well-known principle of degradation of available energy; our law of decay is nearly the same thing. What then will result from establishing the principle of equality as a more fundamental matter?

We may refer to the common mathematical expressions such as Grad P, Div V and Curl V, where P and V stand for any physical scalar and vector quantity. The existence of these means that there is inequality in the field of the scalar or vector. By the principle of tendency towards equality, there must happen something tending to equality in abatement of the inequality. Thus at once follows for a scalar field

$$\frac{\partial M}{\partial t} = F = \text{grad } P,$$

where F is some quantity like force which acts to decrease the gradient of P, which may be such a quantity as atmospheric pressure or electric potential, and M is some other quantity such as momentum or electric charge multiplied by suitable coefficients by whose change the gradient is decreased. This equation is for simple inequality. If there are more fields of inequality coexisting, those effects must be added together. We have the same kind of equations in the theory of potential, heat flow, electricity and magnetism, diffusion, hydrodynamics, and so on. Indeed the fundamental law of Newtonian mechanics, represented by the Lagrangian equation[1] has the same form as above. Only from the law of degradation of available energy, it is difficult to derive such equations directly. The principle of equality has more application. We know another kind of inequality—atomic inequality—for which we can derive the principle of equipartition of energy of Boltzmann as well as of Taylor and Richardson[2] for turbulent motion.

Thus the principle covers very wide regions of natural phenomena,

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[1] The equation is $\frac{\partial(T+V)}{\partial q_i} = \frac{d}{dt}\frac{\partial T}{\partial q_i}$.

This equation sometimes represents decay and sometimes growth. When V stands for the force-function of elasticity, electricity and magnetism, etc., the case is decay. When ($-$V) stands for gravitational potential, the result is growth. A great many results can be derived from this relation, and from the equation

$$\frac{\partial B}{\partial t} = \kappa \text{ curl } E,$$

which will be mentioned in a separate paper.

[2] See § 10.

and if we consider it in connection with the principle of growth, then it is much more interesting.

§ 10. *Decay of Vortices and the Idea of Vortical Generations.*—In order to get clearer ideas of equalisation, we shall now come back to the decay of vortices. As pointed out in my previous paper, vortices in nature represent a process of dissipation of energy. They get energy from the surrounding field. The first process in them expresses the tendency towards symmetry, which, as explained before, is one step towards equality. To fix the idea, we shall take the simplest case into consideration. In the state of symmetry with respect to the axis of rotation, the velocity of the fluid element is a function of the distance from the axis only. It is uniform along any circular orbit having its centre on the axis, but cannot be uniform along a radius vector. Hence the natural tendency towards equality demands something more, so that, as has been observed very often, secondary vortices are produced as means for further equalisation where the convergence of velocity has taken place in consequence of changing velocity due to viscosity, especially when the central core of the original vortex has lost its intensity by frictional action, having no available supply of new energy.[1] These secondaries develop to some extent at the cost of the energy of the original vortex. When there is no chance to get energy from anything else, then each of them tends to symmetry and again divides itself into smaller vortices. Such a process is repeated several times with descending dimensions, so that at last vortices become so small that energy is sensibly distributed quite evenly among every elementary portion of the fluid, and the final equality is attained and the activity comes to an end.[2]

In connection with the above process we find certain dimensions of vortices are conspicuous because they occur with maximum frequency. The children are smaller than the parent vortex and each is nearly of the same size as the others. The grandchildren are still smaller and also nearly uniform in size, and so on. For the sake of convenience we shall call these *vortical generations.*

When the viscosity becomes effective compared with the reduced intensity of the vortex, the final stage comes very soon, intermediate vortices cannot exist, the motion apparently gradually subsides keeping the general type of whirl motion.

Noteworthy facts in this line have been found by G. I. Taylor[3] and L. F. Richardson.[4] Their law is the tendency to equipartition of turbulent

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[1] This phenomenon can be easily observed in a cup of cocoa, but not in a cup of dilute tea. Mr. Richardson has suggested that it must be due to viscosity. In the equation of motion

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+\text{etc.}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\mu\frac{\partial^2 u}{\partial x^2}+\text{etc.},$$

the kinematic terms are of second degree of u, while those of viscosity are of first degree. Hence amalgamation and symmetry may occur when velocity is great, while production of secondaries when velocity is small.

[2] About the process, see also Fujiwhara, S., *loc. cit.* §§ 4 and 5. Mr. L. F. Richardson is of quite the same opinion ("Weather Prediction by Numerical Process," p. 66):

Big whirls have little whirls
That feed on their velocity,
And little whirls have lesser whirls,
And so on to viscosity.

[3] Advisory Committee for Aeronautics, *Reports and Memoranda*, Nos. 304, 345, 598.

[4] Richardson, L. F., "The supply of energy from and to atmospheric eddies," *London, Proc. R. Soc.*, **97** (ser. A), 1920, p. 370.

energy between the three components of velocity. The result is quite in accordance with the above principle of equality. Taylor showed, however, that when the turbulence takes place near the ground the eddy motion with a vertical axis predominates. He demonstrated the fact for the first few metres above the ground, while I found it for the first few hectometres or kilometres above the ground. Their treatment applies to the case of eddies which consist of small whirls with diameters of a few metres. But when the dimension of whirls concerned is large enough, they show the influence of the earth's surface even in the height of a few kilometres above the ground, and in virtue of the tendency to symmetry, the whirls with vertical axis predominate. I observed the fact many times in the vortical formation of clouds.

The behaviour of revolving filaments described by Prof. Hale[1] six years ago and used for the explanation of the sunspot phenomena is also easily explained from the principle of the tendency towards symmetry.

§ 11. *Relation of the Law of Decay to the Law of Growth.*—When the tendency to equality—that means the process of decay—is well understood, then naturally the big question, "Is our universe decaying?" will arise in every ingenious mind. We know that there are various kinds of evolution by which concentration of energy takes place. This is obviously the inverse phenomenon of decay, and the principle which governs evolution must be opposite to the principle of equality. Hence it must be *a principle of tendency towards inequality* or *a principle of disequalisation.* The former is the principle of dissipation, so that the latter must be the principle of the concentration of energy, that is to say, the principle of animate growth, by the action of which the world is kept alive in spite of all the power of the action of decay. Thus the answer "No" to the former question seems to be correct.

But when we approach the further consideration of the actual mechanism of growth and decay, we may perceive that growth and decay are always associated one with the other, and according to the dimensions of the region to which our attention is fixed, sometimes one and sometimes the other presents itself in the foreground. For example, if we fix our attention on those individual vortices which are produced at a street corner on a windy day, the growth of the vortices is one of the most remarkable features which evidently sets in as the dissipating machinery of the general current of wind. Thus the growth here is carried out at the expense of the major system. Meanwhile the general current of the wind may belong to a cyclonic system in which the animate growth is conspicuous, that is to say, in a cyclone a greater velocity can be attained than that which has occurred before, or that which exists in the surrounding field, though the energy for such intensity comes from that field. Thus the dissipation takes place in consequence of the former or simultaneous accumulation. Again the accumulation of energy in the cyclone means the dissipation in the surrounding field, which may be the field of a monsoon system, or of the general circulation. These systems are again circulating systems and subject to decay and animate growth of some kind.

Thus far the analogy can also be drawn from the oceanic circulation from which are derived various growths down to minor vortices with diameter of a few centimetres.

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[1] Hale, G. E., and Luckey, G. P., "Some vortex experiments bearing on the nature of sunspots and flocculi," *Washington, Proc. Nat. Acad.*, **1**, 1915, p. 385.

Probably there will be no end of the mutual embracing principles of growth and decay, *i.e.* the accumulation and distribution in both directions towards macro-cosmos and micro-cosmos. The general relation seems to be nearly the same in every cosmos in so far as a proper scale is used suitable for measurements in that cosmos. In consequence it is very probable we may find the application of these principles of decay and growth in the phenomena of the astronomical universe as well as in the atomic world, and also in biological phenomena.

Thus, probably, though not yet quite certainly, the question stated at the beginning of this section may rightly be answered "Yes" as well as "No," because so far as our vortical system is concerned no animate growth exists without accompanying dissipation. These are not independent actions at all, but only the different expressions for the phases, or preferably sides, of one and the same process in nature.

IV. MATHEMATICAL CONSIDERATIONS.

§ 12. *Increase of Kinetic Energy of Vortical Field by Approach of Two Vortices.*—As proved in the hydrodynamics of an ideal fluid, the kinetic energy of the field of vorticities has an expression under the condition of no motion at infinity,[1]

$$\mathrm{T} = \frac{\rho}{8\pi}\iiiint\!\!\iint \frac{\xi\xi' + \eta\eta' + \zeta\zeta'}{r}\,dxdydzdx'dy'dz',$$

where ρ is the density, ξ, η, ζ and ξ', η', ζ' are components of any two vortical filaments in the field, x, y, z and x', y', z' denoting their respective positions, and r being their mutual distance.

From this equation we can see at once that when the vortices in the field approach nearer together, the total kinetic energy increases, because r decreases in general. This must also be true to some extent for the actual vortices in nature, though these do not follow the law of conservation of vorticity as the field of an ideal fluid does.

We cannot, however, see in the above equation where energy comes from, nor follow the case for the amalgamation of vortices, hence we shall take a different way of investigation.

§ 13. *Mathematical Expression of Energy Transmission.*—L. F. Richardson has given the equation for transmission of energy to an eddy system already,[2] *i.e.*

$$\frac{\partial \mathrm{E}'}{\partial t} = -\frac{2\mu_c\pi^2}{\rho l^2}\mathrm{E}' + \iint\left\{\mu\left(\frac{\partial \bar{v}_x}{\partial h}\right)^2 + \mu\left(\frac{\partial \bar{v}_y}{\partial h}\right)^2\right\}dhd\mathrm{A} - \int\left[\frac{g}{\gamma_p}\int_{\mathrm{G}}^{0} c\frac{\partial\sigma}{\partial h}dh\right]d\mathrm{A}, \quad (13.\ 1)$$

where E′ is the energy of eddies concerned. The term on the left-hand side is the rate of growth of E′. The first term on the right-hand side is the loss of energy in the form of heat due to molecular viscosity μ_c, l is the linear dimension of a typical eddy. The second group is the gain of energy from the mother current, whose component velocities are $\bar{v}_x$ and $\bar{v}_y$; h denotes the height, μ is the eddy viscosity. The third group is the loss of energy in stirring an atmosphere in stable equilibrium,

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[1] Lamb, "Hydrodynamics," 4th ed. p. 210.

[2] Richardson, L. F., *loc. cit.*, formula (5. 2). * Wrong sign in his paper.

g is the acceleration of gravity, γ_p the specific heat of air at constant pressure, σ the entropy per unit mass of atmosphere, h the height, G is the ground limit of the integral, and A the area of a column; c is eddy-conductivity. Terms with negative sign are of passive character in an atmosphere stable when at rest, and they can affect the growth of the eddy but cannot be the cause of it.[1] The only cause of the eddy motion is found in the function of the second group on the right-hand side.

In this equation we can clearly see that the inequality, or, in better words on this occasion, the heterogeneity, of the mother current expressed by $\partial\bar{v}_x/\partial h$, $\partial\bar{v}_y/\partial h$ is the essential condition for the eddy formation. The eddy process is certainly the phenomenon of dissipation. *The regulated energy of the mother current changes to haphazard, and consequently less available energy of eddies.* Thus the above equation is the equation of dissipation and at the same time the equation of accumulation. So that this is the mathematical demonstration for the inference made in § 11 for the mutually embracing features of decay and growth.

§ 14. *Characteristic Energy Equation for Growth.*—As explained in § 10, the member of one family of eddies, *i.e.* each generation, has appropriate average dimension, and the order of dimension jumps from one generation to the other, so that if we want to examine the rate of change of energy content of one generation of eddies, we must count (i.) the gain from the major generation, (ii.) the loss to the minor generation, and (iii.) gain or loss in the form of thermal, potential, electrical or other energies. To simplify the matter, we shall consider the case in which only the gain and the loss of (i.) and (ii.) are existing.

According to L. F. Richardson,[2] the gain of energy from the major system is

$$\frac{\partial E'}{\partial t} = \iint \mu \left\{ \left(\frac{\partial \bar{v}_x}{\partial h} \right)^2 + \left(\frac{\partial \bar{v}_y}{\partial h} \right)^2 \right\} dh\,dA, \quad . \quad . \quad (14.\ 1)$$

whose meaning was explained in § 13. When the height of the main current is kept nearly constant, and the variation of velocity according to the height follows a simple rule, then the above expression is reduced approximately to a form

$$\mu \left[\frac{\bar{v}_H}{H} \right]^2 H\,.\,A = \mu b(E_m - E_{mn}), \quad . \quad . \quad (14.\ 2)$$

where E_m means the total kinetic energy of the mother system, E_{mn} its lower limit, and b is a constant depending upon the distribution of velocity, etc. The eddy viscosity μ changes its value according to the circumstances. From the table given by Richardson as well as others,[3] it seems very likely that the larger or stronger the eddies, the greater is the value of μ. Consider also the actual mechanism at the boundary of a general drifting current. It is obvious that the smaller eddies produce smaller disturbances in the general current, *i.e.* smaller stirring action or smaller dissipation. Thus the eddy vicosity μ must be a function of the intensity of the eddies themselves. So that we have

$$\mu = f(E),\ \frac{df}{dE} > 0, \quad . \quad . \quad . \quad . \quad (14.\ 3)$$

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[1] The last term can be a cause when the atmosphere is unstable.

[2] Osborne Reynolds has given a more general expression than this. Here I do not like to get into more complication in order to obtain an idle generalisation.

[3] "Some measurements of atmospheric turbulence," *Phil. Trans. R. Soc.*, **221** (ser. **A**), pp. 20-23.

where E is the energy of the eddies concerned. We do not yet know the function $f(\mathrm{E})$, so that as a first trial we shall put

$$\mu = a\mathrm{E},\ a > 0. \quad . \quad . \quad . \quad . \qquad (14.\ 4)$$

Then the expression of (14. 2) becomes

$$ab\mathrm{E}(\mathrm{E}_m - \mathrm{E}_{mn}). \quad . \quad . \quad . \quad . \qquad (14.\ 5)$$

Let the energy of the minor system or "children eddies" be denoted by E_c, then, just as above, the energy of the eddies concerned will be dissipated to the minor ones at the rate

$$a'b'\mathrm{E}_c(\mathrm{E} - \mathrm{E}_n). \quad . \quad . \quad . \quad . \qquad (14.\ 6)$$

Then we shall have

$$\frac{d\mathrm{E}}{dt} = ab(\mathrm{E}_m - \mathrm{E}_{mn})\mathrm{E} - a'b'\mathrm{E}_c(\mathrm{E} - \mathrm{E}_n). \quad . \quad . \qquad (14.\ 7)$$

For the rate of change of E_c and E_m we must also have similar equations, so that

$$\frac{d\mathrm{E}_c}{dt} = a'b'\mathrm{E}_c\mathrm{E} - a''b''\mathrm{E}_c(\mathrm{E}_c)_c, \quad . \quad . \qquad (14.\ 8,\ 1)$$

$$\frac{d\mathrm{E}_m}{dt} = a_1b_1(\mathrm{E}_m)_m\mathrm{E}_m - ab\mathrm{E}_m\mathrm{E}. \quad . \quad . \qquad (14.\ 8,\ 2)$$

And so on for $(\mathrm{E}_m)_m$, $[(\mathrm{E}_m)_m]_m$, . . . $(\mathrm{E}_c)_c$, $[(\mathrm{E}_c)_c]_c$, . . (14. 8)

we shall have any number of similar equations.

§ 15. *Solution for Two Vortical Generations.*—Let us first consider the simplest case where there are only two generations of vortices, and the conservation of energy existing between them, then we shall have

$$\mathrm{E}_m - \mathrm{E}_{mn} + \mathrm{E} = \text{constant} = \mathrm{E}_w, \text{ say}, \quad . \quad . \qquad (15.\ 1)$$

$$\frac{d\mathrm{E}}{dt} = ab\mathrm{E}(\mathrm{E}_w - \mathrm{E}). \quad . \quad . \quad . \qquad (15.\ 2)$$

The solution of the equation is

$$\frac{\mathrm{E}}{\mathrm{E}_w - \mathrm{E}} = \frac{\mathrm{E}_0}{\mathrm{E}_w - \mathrm{E}_0} e^{ab\mathrm{E}_w t} = \mathrm{S} \text{ (say)}, \quad . \quad . \quad . \qquad (15.\ 3)$$

where E_0 is the value of E at $t = 0$.

From this we can solve for E, so that

$$\mathrm{E} = \frac{\mathrm{S}}{1 + \mathrm{S}}\mathrm{E}_w = \frac{\mathrm{E}_0\mathrm{E}_w e^{ab\mathrm{E}_w t}}{\mathrm{E}_w - \mathrm{E}_0 + \mathrm{E}_0 e^{ab\mathrm{E}_w t}} \quad . \quad . \quad . \qquad (15.\ 4)$$

The rate of change of E is

$$\frac{d\mathrm{E}}{dt} = ab\mathrm{E}(\mathrm{E}_w - \mathrm{E}) = ab\frac{\mathrm{E}^2}{\mathrm{S}} \quad . \quad . \quad . \qquad (15.\ 5)$$

$$= \frac{ab(\mathrm{E}_w - \mathrm{E}_0)\mathrm{E}_0\mathrm{E}_w^2 e^{ab\mathrm{E}_w t}}{(\mathrm{E}_w - \mathrm{E}_0 + \mathrm{E}_0 e^{ab\mathrm{E}_w t})^2}. \quad . \quad . \quad . \qquad (15.\ 6)^1$$

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[1] Equation 15 (6) expresses the rate at which the energy of a system of vortices grows at the expense of the energy available in consequence of an assumed increase of velocity with height in the original current. The development of the equation is difficult to follow, partly because the author makes a short cut in the integration of equation 14 (2) with very slender justification, and partly because the definitions of the symbols and their relations are not always clear. Without attempting to remove the difficulties, we may note that equation 15 (6) is of such canonical form that whatever may be the particular coefficients involved something of like form has to be reached as an algebraical expression of the ideas which Dr. Fujiwhara has in mind. Readers of the paper on thinking over the subject may be able to express the development of the ideas in more vigorous algebraical terms. In the meantime the guidance in examining the phenomena of weather and weather maps which the probable or possible existence of such an equation provides is in itself acceptable.

In like manner the editors cannot be sure that they have given full expression to the

The next diagram, Fig. 2, shows the general character of these curves, which are gained by putting $E_w = 1$ and $E_0 = 0{\cdot}01$.

So far as I know the typical curves of the simple growth of nearly all living creatures very closely resemble these curves.[1]

A very interesting result in the above solution is that when $E_0 = 0$, there is no growth at all. E_0 is the primary energy or, so to speak, the energy of the germ. *Hence we can infer that for the animate growth the germ is absolutely necessary.*[2]

At the start of this section we assumed that E_m is the total energy of the mother current. We can apply the above calculation to the case when E_m stands for the energy of the limited portion of the mother current, beyond which the action of the eddies concerned cannot reach.

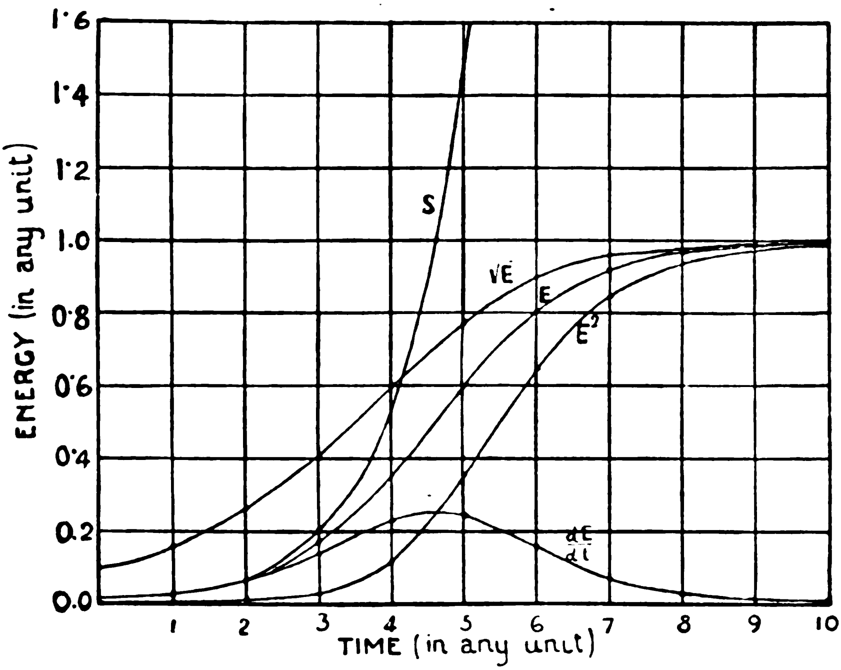

FIG. 2.—Curves for growth. S, E, $\sqrt{E}$ and E^2, and $\frac{dE}{dt}$.

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author's meaning in the intricate algebraical processes of sections 16 to 22. But the reasoning leads up to canonical forms which express the author's ideas of growth and decay of vortices. If with him we assume as a working hypothesis that growth and decay of cyclones are real phenomena, we may almost equally assume that the equations which represent the process must approximate to those forms. The conception of the idea and the formal demonstration of the details of its algebraical expression will appeal with quite different force to different classes of students of nature.

[1] *E.g.* Brailsford Robertson's formula for the growth of plants is

$$\log \frac{x}{A - x} = \kappa(t - t_0),$$

which is quite the same as (15. 3).

[2] See § 31 for the seeds of atmospheric or water vortices. This principle is to be seen also in Richardson's paper, *loc. cit.*, *Proc. R. Soc.*, **97**, p. 364.

§ 16. *Case for no Conservation of Energy.*—We may treat the question otherwise, thus: In the course of events $\partial\bar{v}/\partial h$ and consequently $(\partial\bar{v}_x/dh)^2 + (\partial\bar{v}_y/dh)^2$ will diminish according to the tendency to equality. When the velocity $\bar{v}$ of the mother current reaches the final uniform value $\bar{v}_u$, $\partial\bar{v}/\partial h$ becomes zero and E attains its maximum E_x. At the start when E is sensibly equal to zero, the mother current must have its full strength and its energy is a maximum; we shall denote this by E_{mx}. Then as a rather rough approximation we can have instead of equations (14. 5), (14. 6), and (14. 7),

$$\frac{dE_1}{dt} = abE(E_{mx} - \lambda E), \quad \lambda = \frac{E_{mx}}{E_x} = \text{const.}, \quad . \quad . \quad (16.\ 1)$$

$$\frac{dE_2}{dt} = -a'b'E_c(E - E_n) = -a'b'E_c(E_x - \lambda' E_c), \quad . \quad (16.\ 2)$$

$$\frac{dE}{dt} = abE(E_{mx} - \lambda E) - a'b'E_c(E - E_n). \quad . \quad . \quad (16.\ 3)$$

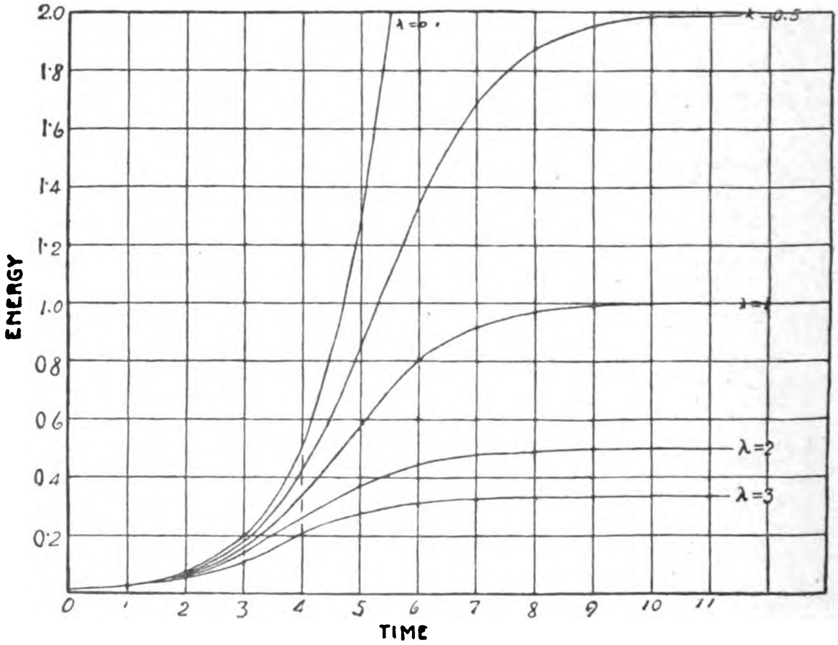

FIG. 3.—Curve E, for various values of λ.

For the case of only two generations we have

$$\frac{dE}{dt} = abE(E_{mx} - \lambda E), \quad . \quad . \quad . \quad (16.\ 4)$$

which leads to the solution

$$S = \frac{E}{(E_{mx} - \lambda E)} = \frac{E}{(E_{mx} - \lambda E)} e^{abE_{mx}t}. \quad . \quad . \quad (16.\ 5)$$

When $\lambda = 1$, the case becomes that for the conservation of energy treated in the last paragraph. In Fig. 3 curves for E from (16. 5) are shown for a few values of λ.

§ 17. *Equations for Three Generations.*—When there are three generations of vortical systems, we shall have from the general equation (14. 7)

$$E_w = E_m - E_{mn} + E + E_c = \text{const.}, \qquad (17.\ 1)$$

$$\frac{dE}{dt} = abE(E_w - E - E_c) - a'b'EE_c, \qquad (17.\ 2)$$

$$\frac{dE_c}{dt} = a'b'EE_c. \qquad (17.\ 3)$$

From the last two equations we have

$$\frac{d(E + E_c)}{E_w - (E + E_c)} = abEdt. \qquad (17.\ 4)$$

From (17. 3) we have

$$\frac{dE_c}{E_c} = a'b'Edt. \qquad (17.\ 5)$$

From these we have

$$a'b'\frac{d(E + E_c)}{E_w - (E + E_c)} = ab\frac{dE_c}{E_c}.$$

From this we get

$$\left(\frac{E_w - (E + E_c)}{E_w - (E_0 + E_{c0})}\right) = \left(\frac{E_c}{E_{c0}}\right)^{\frac{-ab}{a'b'}}, \qquad (17.\ 6)$$

or

$$E = E_w - E_c - [E_w - (E_0 + E_{c0})]\left(\frac{E_c}{E_{c0}}\right)^{\frac{-ab}{a'b'}}, \qquad (17.\ 7)$$

where E_0 and E_{c0} are the value of E and E_c when $t = 0$.

From this and (17. 3) we have

$$\frac{dE_c}{E_c\left[E_w - E_c - [E_w - (E_0 + E_{c0})]\left(\frac{E_c}{E_{c0}}\right)^{\frac{-ab}{a'b'}}\right]} = a'b'dt. \qquad (17.\ 8)$$

By integrating this equation we can solve E_c, and inserting this into (17. 7) we can get the function E.

§ 18. *Approximate Solution for Three Generations.*—The germinal energy E_0 naturally is very small, and E_{c0} must be still smaller compared to E_0. So that, at the beginning, E and especially E_c are quite small. Hence we can neglect the terms containing E_c in the equation (17. 2). The solution is then quite the same as that in the case of two generations at the beginning part. The curve of growth is nearly the same as shown in Fig. 2.

At the end of the process E_c becomes very great compared with E_{c0}. Then the last term in the equation (17. 7) is negligible. Hence we have from (17. 7) and (17. 8)

$$E = E_w - E_c, \qquad (18.\ 1)$$

$$\frac{dE_c}{E_c(E_w - E_c)} = a'b'dt \qquad (18.\ 2)$$

The solution for E_c here is quite similar to that of E in § 15, the only difference being $a'b'$ in the place of ab. Hence and from (18. 1) the decay curve for E has a just reversed form of the growth curve, the steepness of its slope being the only difference.

The maximum value of E is calculated from equating (17. 2) to zero, that means $dE/dt = 0$. Combining this with (17. 7), and eliminating the corresponding value of E_c, we get after some transformation

$$E_w - E = (ab + a'b')\,(a'b')^{\frac{-a'b'}{ab+a'b'}}\,(ab)^{\frac{a'b'-ab}{ab+a'b'}}\,E_{c0}^{\frac{ab}{ab+a'b'}}$$
$$\times\,[E_w - (E_0 + E_{c0})]\,\frac{ab+a'b'}{a'b'}.$$

The results are shown in Fig. 4 for a few values of $a'b'$.

§ 19. *Special Case for* $ab = a'b'$.—For this case we get from (17. 7) and (17. 8)

$$E = E_w - E_c - \frac{A}{E_c},\ A = E_{c0}[E_w - (E_0 + E_{c0})] \qquad . \quad (19.\ 1)$$

$$\frac{-dE_c}{E_c^2 - E_wE_c + A} = a'b'\,dt = dT,\ \text{say}.$$

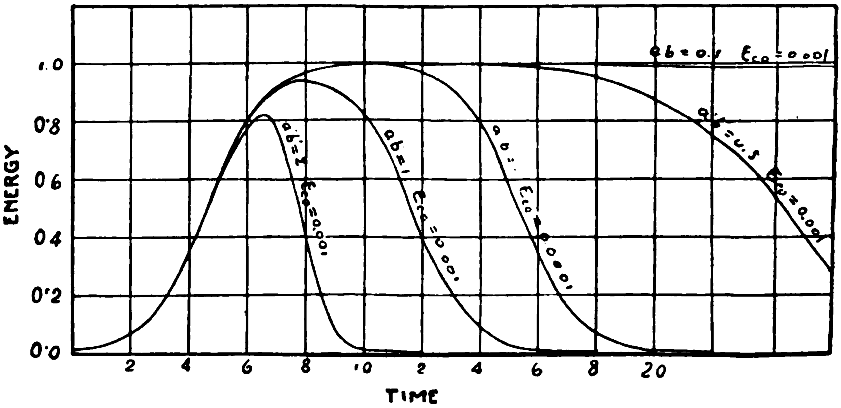

FIG. 4.—Curves of growth and decay for various values of rate of decay.

By integrating this equation we have

$$T = \frac{\sqrt{E_w^2 - 4A} - E_w + 2E_c}{\sqrt{E_w^2 - 4A} + E_w + 2E_c} = \frac{\sqrt{E_w^2 - 4A} - E_w + 2E_{c0}}{\sqrt{E_w^2 - 4A} - E_w + 2E_{c0}}\,e^{a'b'\sqrt{E_w^2 - 4A}\,t} \qquad (19.\ 2)$$

Or
$$T = T_0 e^{a'b'\sqrt{E_w^2 - 4A}\,t}$$

and
$$E_c = \frac{1}{2(1+T)}\left[\left(\sqrt{E_w^2 - 4A} + E_w\right)T - \sqrt{E_w^2 - 4A} + E_w\right]. \qquad (19.\ 3)$$

By substituting this value of E_c in (19. 1) we can get E. The curves for E are shown in Fig. 4.

§ 20. *The Effect of Multitude of Children and Grandchildren Whirls.*—Suppose the case that there is only one mother current, n whirls in the children eddies, and nm whirls in grandchildren eddies. n and m are integers and naturally are rather great. Then the general equation (14. 7) becomes

$$n\frac{dE}{dt} = nabE(E_m - E_{mn}) - n^2ma'b'E_c(E - E_n).$$

Or

$$\frac{dE}{dt} = abE(E_m - E_{mn}) - nma'b'E_c(E - E_n). \quad . \qquad . \quad (20.\ 1)$$

So that the asymptotic value of E diminishes itself to $1/n$, and the rate of the growth diminishes.

For the case of no conservation of energy we have from (16. 3)

$$\frac{1}{n}\frac{dE}{dt} = abE\left(\frac{E_{mx}}{n} - \lambda E\right) - ma'b'E_c(E_x - \lambda'E_c). \qquad . \quad (20.\ 2)$$

§ 21. *Case of Constant Dissipation.*—Suppose a case where the capacity of the dissipating system is very great, and no sensible accumulation takes place, then we shall have from (20. 2) for $a=a'$

$$\frac{1}{n}\frac{d\mathrm{E}}{dt}=ab\mathrm{E}\left(\frac{\mathrm{E}_{mx}}{n}-\lambda\mathrm{E}\right)-mab'\mathrm{E}\epsilon, \qquad . \qquad . \qquad (21.\ 1)$$

where $mab'\epsilon$ is the constant rate of dissipation.

The solution of the above equation is

$$\mathrm{S}=\frac{\mathrm{E}}{\frac{\mathrm{E}_{mx}}{n}-\frac{mb'\epsilon}{b}-\lambda\mathrm{E}}=\frac{\mathrm{E}_0}{\frac{\mathrm{E}_{mx}}{n}-\frac{mb'\epsilon}{b}-\lambda\mathrm{E}_0}e^{ab\left(\mathrm{E}_{mx}-\frac{nmb'}{b}\epsilon\right)t}. \qquad (21.\ 2)$$

The growth curve of E is nearly the same as that obtained in § 16; the only difference is that $\frac{\mathrm{E}_{mx}}{n}-\frac{mb'\epsilon}{b}$ stands here for E_{mx} there.

When E gets the value to satisfy

$$\frac{\mathrm{E}_{mx}}{n}-\lambda\mathrm{E}-\frac{mb'}{b}\epsilon=0,$$

$d\mathrm{E}/dt$ becomes zero and E attains its maximum value, and the gain and loss balance in such a way that

$$\text{Gain}=ab\mathrm{E}\left(\frac{\mathrm{E}_{mx}}{n}-\lambda\mathrm{E}\right)=\frac{mab'}{\lambda}\left(\frac{\mathrm{E}_{mx}}{n}-\frac{mb'}{b}\epsilon\right)\epsilon=\text{Loss}.$$

In this case the mother current must also have the same amount of the supply of energy in order to maintain all of the families without decay.

§ 22. *Two Generations with Constant Supply and Constant Dissipation of Energy.*—In this case we have equations

$$\frac{d\mathrm{E}_m}{dt}=p\mathrm{E}_m-nab\mathrm{E}(\mathrm{E}_m-\mathrm{E}_{mn}), \qquad . \qquad . \qquad . \qquad (22.\ 1)$$

$$n\frac{d\mathrm{E}}{dt}=nab\mathrm{E}(\mathrm{E}_m-\mathrm{E}_{mn})-n^2mab'\mathrm{E}\epsilon. \qquad . \qquad . \qquad (22.\ 2)$$

p is the fractional rate of supply. From these we can eliminate E_m and get an equation of second order and second degree of E, $d\mathrm{E}/dt$ and $d^2\mathrm{E}/dt^2$, which is very difficult to solve. We can, however, deduce the general trend of E_m and E from these equations.

E_0, the initial value of E, is naturally very small, so that E_m grows according to the constant rate of supply p, and passes the stage where

$$\mathrm{E}'_m=\mathrm{E}_{mn}+\frac{nmb'}{b}\epsilon. \qquad . \qquad . \qquad (\text{Stage } 1)$$

Then E starts to grow, but still very slowly, because E is still very small. When E increases to the value

$$\mathrm{E}''=\frac{p\mathrm{E}''_m}{nab(\mathrm{E}''_m-\mathrm{E}_{mn})}, \qquad . \qquad . \qquad (\text{Stage } 2)$$

E_m gets its maximum value, and thence begins to decrease while E is still increasing. When E_m comes back to the value E'_m, E gets its maximum value, and thence begins to decrease (Stage 3). Then again the relation

$$\mathrm{E}'''=\frac{p\mathrm{E}'''_m}{nab(\mathrm{E}'''_m-\mathrm{E}_{mn})} \qquad . \qquad . \qquad (\text{Stage } 4)$$

will be established and E begins to increase. Thus again the Stages 1, 2, etc., will be repeated. When E″ happens to be equal to E‴, then the process is quite periodic; but in general E″ is not equal to E‴, and consequently E″ in one cycle is not equal to the same of the next cycle, and so with E'''. Thus the process is cyclic but not periodic, and we can find an average period from which the actual period of one cycle deviates more or less, sometimes positively and sometimes negatively. The steepness of the curves of E and E_m is in general great when they are great and is small when they are small, so that the curves start to increase very slowly, but begin to decrease very quickly. In some particular cases Stage 4 may occur before Stage 3 is reached. In such cases a small minimum and a small maximum of E_m takes place before Stage 3 is reached, and naturally the minimum value of E may be unusually small. It might be of some interest to consider such process in connection with the sun-spot curve.

V. APPLICATION TO METEOROLOGICAL PHENOMENA.

§ 23. *The Growth of Tornadoes by Amalgamation.*—According to the report of H. Billett,[1] the tornado which passed over South Wales on October 27, 1913, increased its intensity after amalgamating with a secondary one at about a mile north of Treforest. He writes on p. 8 of his report: "and does not seem to have done much damage till it got to Treforest, about a mile distant in a direction a little east of north; there the first building to suffer was the generating station," etc., and on the next page, and also in the chart attached thereto, he shows that a secondary storm had united with the principal one at a distance of a mile to the north of Treforest. Such cases may occur naturally with other tornadoes.

§ 24. *Approach of Two Cyclones, and Separation of a Cyclone from an Anticyclone.*—This is the general rule of meteorology known as Okada's law among Japanese forecasters. Prof. Okada discovered the law many years ago.[2] When a cyclone moving from west to east is followed by an anticyclone, its velocity is accelerated, and when it is preceded by an anticyclone its velocity is retarded. With a succession of cyclones the opposite is the case. These phenomena show that the laws explained in §§ 5 and 6 are applicable to the atmospheric whirls such as tornadoes, cyclones, and anticyclones.

§ 25. *Increase of the Intensity of Cyclones by Amalgamation.*—This is also a very remarkable fact commonly known among Japanese forecasters. I have a large number of actual examples of it. I will take one case from the Japanese daily weather charts of the Central Meteorological Observatory, Tokyo. On the morning of the 1st January 1918, a very shallow depression (766 mm.) was centred in the Yellow Sea. From its barometric depth (764 mm.) in the noon chart we see that this increased, and a new one (764 mm.) had been born in the Eastern Sea of China, and another one (762 mm.) in the Japan Sea. During that afternoon and night they increased their depth and moved towards the east, approaching to each other, and on the morning of the 2nd five centres (754, 752, 752, 754, 754 mm.) were to be found on the chart embraced by common isobars 756 and 758 mm. By noon of the same day they had united into one and the intensity had increased, and on the next morning there was an intense cyclone with the central isobar, 740 mm., situated in the east of Hokkaido. Such cases occur very often in the vicinity of Japan. We can find similar examples in the weather charts of different parts of the world. For example, in the American Weather Map, U.S.A. Weather Bureau, for the days 18th to 21st October 1921, we can see that one cyclone from the middle States moved towards E.N.E. and declined a little on the 19th, but amalgamating with another one on the 20th it got new strength and grew vigorously.

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[1] "The South Wales tornado of October 27, 1913," *London, Meteor. Off., Geophys. Mem.* No. 11.

[2] Okada, T., "Kisyogaku Kowa" (Manual of Meteorology, written in the Japanese language, 1907). Indeed, the knowledge of this law was one of the strongest motives for me to enter upon the present study.

It is quite certain that there are many small whirls of very slow angular motion in the atmosphere. We can see it by the actual observation of clouds, and also can recognise it in the minute variation of wind directions in the weather maps. Any cyclone with converging motion can grow by absorbing small whirls of the same sense of rotation which are not clearly shown in weather maps, though these are not its only food. Generally speaking, cyclones can be fed with atmospheric vorticity of the counter-clockwise rotation.

§ 26. *Decay of Cyclones by Division.*—As shown in § 4 and § 9, a whirl has the property of dividing itself into two or more whirls in its declining phase. Such is also the case with a cyclone. Typhoons, especially in October, passing the Japanese islands, show this character very often. Japanese forecasters were often alarmed by an approaching typhoon with threatening features covering wide areas. But when it drew near it was discovered to have two or more centres, and hence proved to be rather mild. The typhoon on the 8th to 11th October 1917 is one example. It was very threatening when it came up to the south of Kyusyu from the east of Formosa; the wind at Cape Sata exceeded 40 m/s on the morning of the 10th. But when it came near Sikoku it began to divide, and on the morning of the 11th, when it passed the Main Island, two centres were clearly shown on the weather chart.[1] These were very quickly filled up. At noon rain ceased to fall throughout the vicinity, and on that evening there was scarcely any mark of it remaining. It is very probable that the orographic conditions may help the formation of the secondaries. But it is also very probable that the development of a tornadic centre accompanied by a heavy downpour of rain is also very powerful to destroy the original or mother cyclone, as Sir Napier Shaw pointed out.[2] We have had examples of this phenomenon occurring in the vicinity of Japan. (Takayama, S. Heavy downpour at Tokusima.)

§ 27. *The Applicability of the Theory of Growth and Decay to the Phenomena of a Cyclone.*—In order to develop the formulæ of growth and decay, we started from the equation (14. 1) in the last chapter, which concerns the vertical variation of the wind velocity. It is equally correct if we change the meaning of h in that equation and use it for the horizontal distance measured normal to wind direction. Then E means the eddying energy of whirls with vertical axes. Let us imagine a cyclone which has a nearly symmetrical current round its axis, embedded in the field of flow of the mother current. We shall denote the velocity due to this by $\bar{v}$, and that of the cyclone by v'. Let us follow the same operation made by Osborne Reynolds[1] and by Lewis F. Richardson[2] for the eddy motion. Then we shall find that those terms containing $\bar{v}v'$ do not vanish when integration is taken over the whole area of the cyclone, as it does in eddy motion. But their values are so small compared with the other terms containing $\bar{v}^2$ and v'^2 that we can neglect them for the present approximation. Thus we may extend the use of the above theory to treat the energy of a cyclone, and also a series of cyclones. If this is correct, then the curves of growth and decay of cyclones must have an appearance resembling the curve calculated out in § 18, Fig. 4. Now it is a hard task to reckon the energy of even one cyclone for each stage of its development. It is lucky, however, that the energy curve has a form similar to those of the higher or lower powers of the energy, as shown in Fig. 2. And consequently the linear expressions, consisting of terms of various powers of E, must also have a similar form. We cannot say with any exactness that the energy of a cyclone is proportional to its area, or to its barometric depth at the centre, or to any other characteristic. But these factors, in the present approximation, may certainly be looked upon as a function of E, and it is very probable that their mode of change will follow to some extent that of the energy E. This is, for the present, a mere speculation, but let us try to test it.

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[1] Neither of these two centres was an induced one in the ordinary way, by orographic conditions, because one was situated on the land instead of being in the Japan Sea.

[2] Shaw, *Sir* N., "The travel of circular depressions and tornadoes," *London, Meteor. Off.*, *Geophys. Mem.* No. 12, p. 43.

§ 28. *Actual Curve of Growth and Decay of Cyclones.*—In order to test the above notion, I traced the actual curves of growth and decay of cyclones for which data are near at hand. In Fig. 5 we can see the curves for various dates. Curves *a*, *b*, *c*, *d* represent the increase and decrease of the barometric depth at the centres of four cyclones which visited Europe from the end of August till the middle of September 1921. Data are taken from the *Daily Weather Report* of the Meteorological Office, London, International Section, for that period. Curve *e* represents the same shape as the Chinese cyclone, the data for which are taken from the Japanese daily weather chart of the Central Meteorological Observatory, Tokyo. Curves *f*, *g*, *h*, *i*, *j* and *k* and *l* are those for American cyclones, the data for which are taken from the *Monthly Weather Review*, and the data for the curve *m* are got from the American weather maps, U.S. Weather Bureau, for 16th to 21st October 1921. Among these curves, five, *a*, *b*, *c*, *f*, and *g*, have the same characteristic as those calculated and shown in Fig. 4. Six of them, *d*, *e*, *i*, *j*, *k*, and *l*, indicate the regain of energy after decaying to some extent. These curves have also the same characteristic feature as those of the former group. The cyclone represented by the curve *m* developed in the same way as that of the first group, and reached its maximum and began to decay, but at that time another cyclone approached and united to it. It thus got new strength and grew further in the ordinary way. The curve *n* shows a quite different character. The cyclone for this curve was an erratic one, its track bending so often and so suddenly. This cyclone, therefore, cannot be treated as a whirl getting energy from the mother current as do the others. For the comparison I add here the curve *o* for an American anticyclone. The curve has the same character as *n*, and has no indication of growth and decay as inferred from the theory above.

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[1] "On the dynamical theory of incompressible viscous fluids and the determination of the criterion," *London, Phil. Trans. R. Soc.*, A, **186**, part 1, p. 123.

[2] "The supply of energy from and to atmospheric eddies," *loc. cit.* pp. 355, 357.

The curve *p* is added here by the good will of Sir Napier Shaw. The cyclone for this curve stayed a long time in the vicinity of the English Channel from 27th July to the 6th of August 1917, and special study was made of it. In this curve we can see two maxima of nearly the same strength. Something like amalgamation and division were experienced in the course of this cyclone.

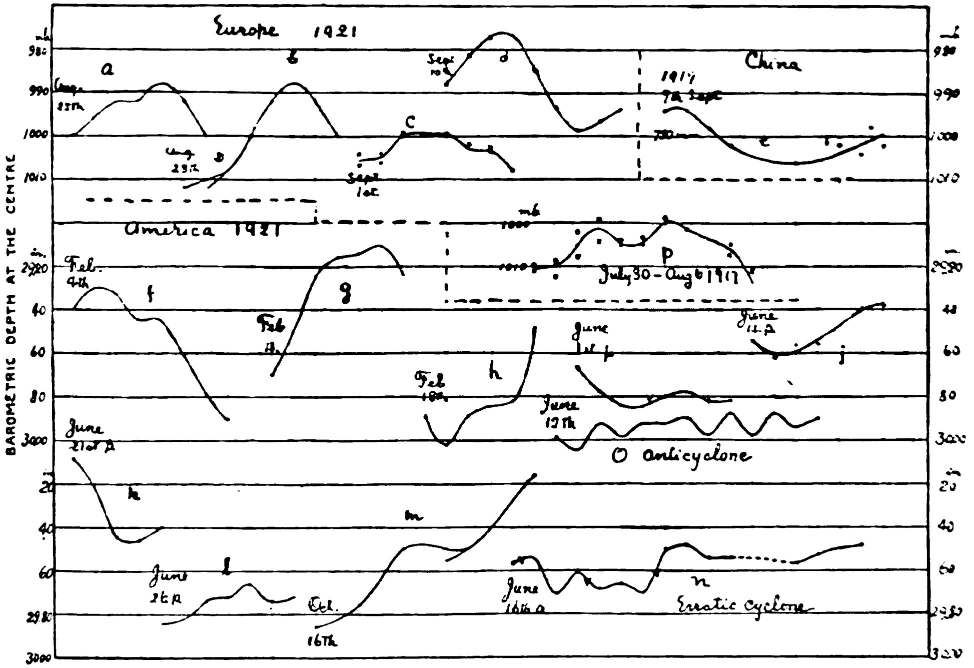

FIG. 5.—Growth and decay curves for cyclones.

↻ Amalgamation occurred. ↓ Approach of another cyclone.
V Sudden change of the direction of the track.

These curves are not taken from examples specially selected for the purpose. They are taken only from data which happened to be near at hand. Selection is only exercised to the extent that those cyclones which appeared in the weather maps for very short intervals are omitted. Hence we can infer that, though the above study is not so perfect as to cover statistically all cyclones in many years, it is very probable that there will be at least three classes of cyclones from the point of view of growth and decay, and one of them shows simple growth and decay; the other may be rather complex, and their curves can be looked upon as the resultant of a number of simple curves of growth and decay; a third class includes erratic cyclones which occur rather seldom. This classification is more conclusive than expected at the end of the last section.

§ 29. *Curves for Sunspots Area.*—Though sunspots are not quite within the province of meteorology, it may be interesting to compare their growth and decay with that of terrestrial cyclones, because they are also thought to be something of a vortical nature. Hence I plotted as ordinates in Fig. 6 the successive areas of each of a series of sunspot groups. The data are taken from the Greenwich observations for 1912; those groups which were observed only for a short time are omitted. Groups Nos. 6988, 7002, and 7006 have growth and decay curves of simple type as calculated theoretically. The curves for Nos. 6977, 6982, 6992 have less prominent maxima after they had passed their principal maxima. This suggests to us that in such a group of spots two or three generations of vortical motion as discussed in §§ 9 and 12 may exist, which will grow successively one after another at the cost of the decay of their respective maternal systems, and decay by giving up their energy to the minor systems. The nature of the curve reminds us of the famous exponential analysis of the disintegration curve of radio-active substances made by Prof. Rutherford. Very likely a similar method may be applied in our case, assuming the simple curve of growth and decay calculated in § 18, Fig. 4, as the unit curve.

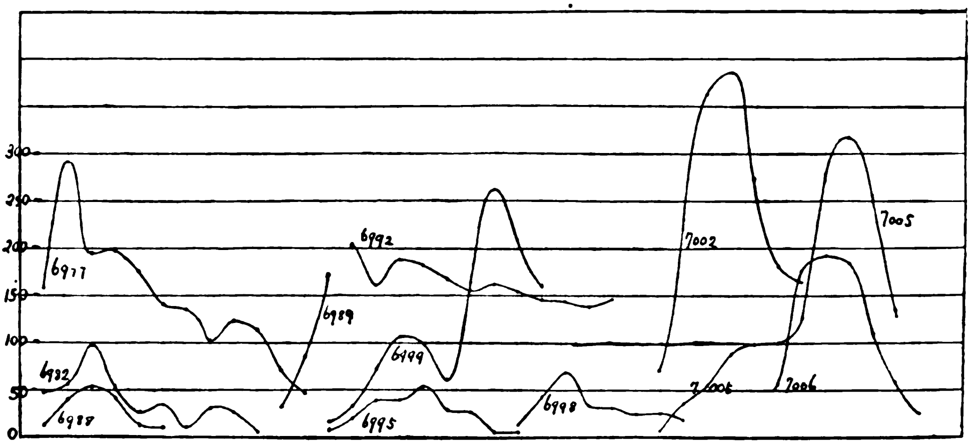

Fig. 6.—Change of area of sunspots groups.
From Greenwich Observation, 1912.
Figures show the group number. Abscissa is number of days.

The curves 6999 and 7005 have the same character as the curve of the American cyclone shown in Fig. 4, *m*. The growth at first in these cases took the ordinary course, *i.e.* very slow at the start, then the rate increased and grew rapidly, and then again became slow and reached the maximum, and then began to decay slowly. At this stage they got new strength to grow, and grew again vigorously.

Thus the growth and decay of a group of sunspots is very likely to be explained from the characteristic property of vortical systems in the same way as applies to that of the cyclones, animate growth occurring in each case. This shows at the same time that the coincidence in form of the curves for cyclones with that calculated is not mere accident.

§ 30. *General Vorticity in Field as Food for Cyclones.*—Now the fact that a cyclone is fed by vorticity of the field has become rather clear. We shall try to advance a step further. In an atmospheric current whose stream lines are nearly parallel and straight, the expression $\partial v/\partial h$ represents the vorticity, where v is the velocity of the current at any spot and h is the distance normal to the current.[1] Take the direction of h to be positive from the low-pressure side to the high, and take the geostrophic wind G instead of the wind near the ground. Then we can test the theory in such a way that the vorticity expressed by $\partial G/\partial h$, which is positive for anticlockwise rotation, must be favourable for the growth of a cyclone, and the negative vorticity, which is clockwise, must be unfavourable. We know that cyclones nearly always take their courses towards the region where the barometer is falling, and avoid the region where it is rising. Hence the falling barometer means the condition favourable to the cyclone. If the theory is correct even approximately, the falling of the barometer must, to some extent, follow or accompany a positive value of $\partial G/\partial h$. It will be interesting to count the number of cases of each association of rising and falling of barometer with positive and negative $\partial G/\partial h$. I could not take complete statistics. I tried it only for a month, September 1921. I picked out the cases from the *Daily Weather Report* of the Meteorological Office, London, International Section. The following table gives the result:[2]

Barometer.							
Rising.				Falling.			
$\partial G/\partial h$.				$\partial G/\partial h$.			
+	−	Nearly zero.	Uncertain.	+	−	Nearly zero.	Uncertain.
5	53	9	20	25	16	9	42
67				50			
Total number of certain cases = 117.							

In this table uncertain cases are mostly due to the rising or falling barometer at Spitzbergen, Iceland, and Azores, where the sign of $\partial G/\partial h$ is not quite certain. Some of them, however, are due to the too much bending and irregularity of isobars.

Ordinarily the wind is strong in the cyclone and weak in the anticyclone, and consequently $\partial G/\partial h$ has a tendency to be negative. This tendency is seen also in the above table. Among 117 obvious cases 69 cases, *i.e.* 59 per cent, are negative, 30 cases, *i.e.* 26 per cent, are positive, and 18 cases, *i.e.* 15 per cent, are neutral. In spite of this tendency we can see the strong association of a falling barometer with positive $\partial G/\partial h$, just answering to the demand of the above theory. We can separate the pure effect of vorticity associated with a falling barometer from that general tendency of $\partial G/\partial h$ to be negative.

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[1] [It has been noted by a reader that this expression for the vorticity omits the terms $\partial v_y/\partial x - \partial v_x/\partial y$, and that they are not negligible in a cyclone because the stream lines are not parallel and straight.—N. S.]

[2] In this table all cases in the morning and evening maps from the morning of the 1st to the morning of the 29th are treated.

Let the probability for the positive, negative, and neutral $\partial G/\partial h$ due to the general tendency be p, q, and r, and that associated with falling barometer be P, Q, and R. Under the action of these two causes the actual cases must have occurred in such a way that

n = the total number of cases $= 50$;

nA = the number of cases in which the falling is associated with positive $\partial G/\partial h = 25$;

nB = that with negative $\partial G/\partial h = 16$;

nC = that with neutral $\frac{\partial G}{\partial h} = 9$;

$$A = \frac{pP}{pP+qQ+rR},\ B = \frac{qQ}{pP+qQ+rR},\ C = \frac{rR}{pP+qQ+rR}.$$

By solving these we get,

$$P = \frac{Arq}{pq - Aq(p-r) - Bp(q-r)} = 0\cdot524$$

$$Q = \frac{Brp}{pq - Aq(p-r) - Bp(q-r)} = 0\cdot148$$

$$R = \frac{Cpq}{pq - Aq(p-r) - Bp(q-r)} = 0\cdot327$$

If the assumption that the two causes are acting independently is correct, we must get the distribution of the number of cases of $\partial G/\partial h$ for the rising barometer.

Thus we have, by using the above value of P, Q, R,

$$n'A' = \frac{qP}{qP+pQ+rR} = 52\cdot2,$$

$$n'B' = \frac{pQ}{qP+pQ+rR} = 6\cdot5,$$

$$n'C' = \frac{rR}{qP+pQ+rR} = 8\cdot3,$$

where $n' = 67$. In the actual case $n'A' = 53$, $n'B' = 5$, $n'C' = 9$, and they are in rather good agreement.

Now returning to the case for the falling barometer, we get the probability for the association with it of positive $\partial G/\partial h$ to be 0·524. This shows clearly that anticlockwise vorticity in the field of the general current acts as a feeder in more than half of all cases. We may increase this figure later, because when compiling the statistics I observed that the neutral and positive $\partial G/\partial h$ were very often associated with the falling barometer when there was a remarkable positive $\partial G/\partial h$ in the district just to windward of the place concerned. The general conclusion to be drawn here is that cyclones are fed certainly kinematically, and by that means they can maintain their animate growth. I must leave the detailed investigation of the above correlation for the future or for any one who would have interest in this line, because I have no time now for it.

§ 31. *Germ of Vortices in Air and in Water.*—For the animate growth of a vortex a "germ" is necessary, as proved in § 15. What is the germ of an atmospheric or water vortex? As proved in hydrodynamics, it is impossible to make or to break up a vortex filament in an ideal fluid.

It is, however, possible in ordinary fluids in nature. These facts may be understood as meaning that an ideal fluid lacks the germs of vortices and a real fluid contains a sufficient number of these germs. An ideal fluid has no viscosity, and ordinary fluids have it. Then viscosity seems to be the effect of the action of those germinal vortices. I cannot answer now exactly on this point, but the fact is that in air as well as in water any number of vortices of the smallest size can be produced in virtue of the viscosity, these smallest can develop to small ones and these again to moderate vortices. Thus there is no difficulty in the formation of a cyclone for the want of a germ.

§ 32. *Inference from Ordinary Hydrodynamics.*—Hesselberg and Friedmann[1] have given the equation for the rate of change of the vertical vorticity in the earth's atmosphere in the following form:

$$\frac{dw_z}{dt} = w_x\frac{\partial v_z}{\partial x} + w_y\frac{\partial v_z}{\partial y} + w_z\frac{\partial v_z}{\partial z} - w_z\theta - \lambda\left(\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y}\right),$$

where x, y, z are rectangular co-ordinates, positive x taken to the east, y to the north, and z upward; v_x, v_y, v_z are the velocity components, and w_x, w_y, w_z the components of vorticity. θ denotes the divergence of the velocity vector and λ is the coefficient of the horizontal component of the deflecting force of the earth's rotation; *i.e.* $\lambda = 2\omega\sin\phi$. The sense of w_z is positive when it is cyclonic.

In order to adapt this equation to the present problem, we shall change its form in such a way that

$$\frac{dw_z}{dt} = \left(w_x\frac{\partial v_z}{\partial x} + w_y\frac{\partial v_z}{\partial y}\right) - w_z\theta_h - \lambda\theta_h, \quad . \qquad . \quad (32.\ 1)$$

where

$$\theta_h = \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y}.$$

Here we can see that the first part of the rate of increase means the increase of the vertical vorticity at the expense of the horizontal vorticity when there is horizontal variation of the vertical velocity component. This latter factor increases as a cyclone develops at least in the beginning, so that the rate of increase of the vertical vorticity will increase with the growth of the cyclone, which is obviously of partly animate character.

The second part in the above equation means the increase of the vertical vorticity produced by its own vorticity in a converging field; inversely it means the decrease in a diverging field. This term has also the animate character.

The third part is produced in a similar manner by the vorticity due to the rotation of the earth. As a cyclone grows the converging motion becomes stronger, and consequently the rate of increase of the vertical vorticity increases as the vorticity increases. Hence this term also has an animate character.

Let us further modify (32·1) into the following form:

$$\frac{\partial w_z}{\partial t} = -\left(v_x\frac{\partial w_z}{\partial x} + v_y\frac{\partial w_z}{\partial y} + v_z\frac{\partial w_z}{\partial z}\right) + \left(w_x\frac{\partial v_z}{\partial x} + w_y\frac{\partial v_z}{\partial y}\right) - \theta_h w_z - \theta_h\lambda. \quad (32.\ 2)$$

The first part of this increase means the increase of the vertical vorticity at a fixed place due to heterogeneity in the general current of air. The phenomena explained in the last paragraph have close relation with this term. In one way this term has inanimate character.

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[1] "Die Grössenordnung der meteorologischen Elemente und ihre räumlichen und zeitlichen Ableitungen." *Veröff. Geophys. Inst. der Universität, Leipzig*, 2te Serie, H. 6, pp. 167, 169.

The next transformation is

$$\frac{dW_z}{dt} = \left[(V_x - v_x)\frac{\partial w_z}{\partial x} + (V_y - v_y)\frac{\partial w_z}{\partial y} + (V_z - v_z)\frac{\partial w_z}{\partial z}\right]$$

$$+ \left(w_x\frac{\partial v_z}{\partial x} + w_y\frac{\partial v_z}{\partial y}\right) - w_z\theta - \lambda\theta, \quad (32.\ 3)$$

where W_z means the vorticity of a moving vertical vortex filament whose component velocities of translation are V_x, V_y, V_z.

If we integrate the above equation over a cyclonic area, whose centre has the velocity V_x, V_y, V_z, we can get corresponding expressions for

$$\iint\frac{dW_z}{dt}dxdy, \quad \iiint\frac{dW_z}{dt}dxdydz, \quad \iiiint\frac{dW_z}{dt}dxdydzdt.$$

The complete treatment of these expressions may be found in another paper.

By observing these equations we can see the similar characteristic way of growth treated in the §§ 5, 6, 13, 14, and 28 with the energy equations from quite a different point of view, which helps to justify the above treatment. The increase of the vorticity by the amalgamation of two or more vortices can also be seen in the expression of the integrated form, but *its mechanism and especially the selective ability of vortical systems, which is essential to animate growth, cannot be expressed in such a way.*

From these equations and from the fundamental fact of animate growth and decay, we can develop a new theory for the mechanism of a cyclone, which is purely meteorological, and will be treated in a separate paper.[1]

As a conclusion to this chapter we can say that the laws of growth and decay are not only applicable to the vortical motion in water, but also govern the atmospheric whirls in a very striking manner.

§ 33. *Comparison of the Vortical Phenomena with Quantum and Allied Phenomena.*—The following characteristics of the vortical phenomena will be worth mentioning:—

(*a*) Water and air vortices can absorb the energy of wave motion, and also can emit it in the form of a wave.

(*b*) From each link of a vortical chain respectively an individual wave front is sent out (see Fig. 2 of my first paper). These fronts from all the links form a common wave front. Near the chain the front has a corrugated form, but after travelling some distance it becomes gradually straight.

(*c*) Vortices are produced forming generations—that is to say, mother system, children system, grandchildren system, and so on. Vortices belonging to one generation have approximately the same order of magnitude, or, in other words, the distribution of magnitude follows some law like the law of probability, having maximum frequency of occurrence at a certain magnitude.

(*d*) The conservation of angular momentum must hold to some extent for such vortices. Vortices of nearly the same size must have nearly the same angular momentum.

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[1] "On the mechanism of extratropical cyclones," third memoir on vortical phenomena, follows this paper, p. 105.

(*e*) One big vortex can swallow many smaller vortices of the same sense of rotation, and from one big vortex many secondaries and tertiaries may be produced and sent out when the phase is divergent. The chain of secondaries thus sent out may transform into wave motion.

(*f*) For the growth of a vortex a germ or the initial value of energy of finite amount, however small, is necessary.

(*g*) A marked feature of vortical phenomena is that every vortex has individuality, while the wave motion is more distinguished by its continuity. Its energy may be treated as being subject to continuous variation, while that of the vortical motion varies also continuously in one way but spontaneously in the other.

(*h*) Vortices make animate growth.

It seems likely that corresponding to these characteristics of vortical motion there exist analogous properties in the phenomena of radiation, specific heat, etc., in connection with atomic structure in view of the quantum theory. I wish to appeal to those philosophers on these lines to take the vortical phenomena again into consideration, as the late Lord Kelvin did, but from a new standpoint.

[To the original typescript was added a sixth part, in which analogies with the conditions and processes of the growth and decay of vortices were sought in other natural phenomena, including the phenomena of life. The subjects thus glanced at included sunspots, the atmosphere of Jupiter, spiral nebulæ, the vortical shapes embodied in the land features of the globe, and the relation of germs and spiral formations to vital growth. At the request of the author the publication of this part, with the exception of what appears here as § 33, has been postponed.]

ACKNOWLEDGMENT.

Since I have written the present paper during travelling I received much help from many persons.

The Japanese Government, Board of Education, and Dr. K. Nakamura, the director of the Central Meteorological Observatory, Tokyo, granted me the government money for travelling and gave me time to accomplish this paper. My thanks are due for their generosity.

Professor T. Okada, when he was in London, recognised the value of the present study, and arranged the above matter and gave me encouragement and advice.

Sir Napier Shaw, under whose patronage and guidance I have written the paper in London at the Imperial College of Science and Technology, was ever so kind, and not only supplied me with all necessary knowledge and data which he possessed, but also took all efforts for the sake of my personal wants. To these two gentlemen my utmost thanks are due.

I got much help and assistance from Dr. G. C. Simpson, the Director of the Meteorological Office, London, Dr. H. Jeffreys, the librarian, and Mr. J. H. James, the mechanician, and other ladies and gentlemen of the same office. I also received much kind advice from Mr. L. F. Richardson.

I got my fundamental idea of the paper twelve years ago when I was a student of the Imperial University, Tokyo, under the guidance of Prof. H. Nagaoka and T. Terada.

I observed the vortical phenomena in air and in water at Bergen amid warm hospitality and kind help of Prof. V. Bjerknes, Prof. H. Helland Hansen, Mr. J. Bjerknes and others in the Geophysical Institute, Bergen.

Indeed a small seed from the East got moisture at Bergen and heat and sunshine in London and could issue a little sprout.

My hearty thanks are due to all the above ladies and gentlemen.

I used the Science Library at South Kensington, London, and gathered useful knowledge., I express my gratitude to the officials there, and also to the English nation for its generosity to foreigners in giving such facilities.

SCHOOL OF METEOROLOGY, SOUTH KENSINGTON,
LONDON, *January* 1922.

NOTE ADDED MARCH 7, 1923.

In a paper by S. Fujiwhara and A. Tveten read at a conference at Bergen on July 27, 1920, a comparison of the magnitudes of certain factors in vortices in air and water was made by a method similar to Helmholtz' treatment of dimensions. Assuming the coefficient of viscosity of water to vary between 0·01 to 0·02, and the coefficient of turbulent viscosity of air to be 5 to 200 c.g.s. units, they found the following relations of magnitudes in air and water:

Linear dimension . . .	380 : 1	to	4,000,000 : 1
Velocity	12·5 : 1	to	50 : 1
Time interval . . .	77 : 1	to	320,000 : 1

Thus corresponding to a water vortex of $\frac{1}{2}$ cm. to 1 metre in diameter, we should have the air vortex 380 metres up to 4000 km. in diameter.

[The discussion on this paper was taken with that on the following paper by the same author. See p. 117.]

ON THE MECHANISM OF EXTRATROPICAL CYCLONES.

(THIRD MEMOIR ON VORTICAL PHENOMENA.)

BY DR. S. FUJIWHARA, F.R.Met.Soc.,
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[Received February 14, 1922—Read February 21, 1923.]

§ 1. *Introduction.*—In my second paper about vortical motion[1] it was shown that extratropical cyclones make animate growth and decay, and get food, *i.e.* energy of vorticity, from the surrounding field for their growth. The present paper is the continuation of the meteorological part of it.

§ 2. *Survey of existing Theories.*—To start with, we must glance at existing theories from the point of view of the change of rotatory motion in cyclones.

In order to examine the increase or decrease of vorticity in the atmosphere, it is very convenient to follow Hesselberg and Friedmann.[2] For the rate of change of vorticity (in vector sense) they give the following equation:

$$\frac{dw}{dt} = \mathrm{K} + \mathrm{D} + \mathrm{W} + \mathrm{F},$$

where K stands for a vector due to kinematic action, D is a vector due to the deflecting force of the earth's rotation, W is the vector due to the heterogeneity of the pressure and density, and F means a vector due to friction. For the complete expression reference must be made to the original paper. They calculated the order of magnitude of each term for the motion in the earth's atmosphere and neglected the small quantities and got the equation for the rate of increase of the vertical vorticity:

$$\frac{dw_z}{dt} = w_x\frac{\partial v_z}{\partial x} + w_y\frac{\partial v_z}{\partial y} + w_z\frac{\partial v_z}{\partial z} - w_z\theta - \lambda\left(\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y}\right),$$

where x, y, z are rectangular co-ordinates, x increasing to the east, y to the north, and z upward; v_x, v_y, v_z are velocity components; w_x, w_y, w_z are components of vorticity; θ denotes the divergence, and λ is twice the vertical component of the earth's angular velocity. The sense of w_z is positive when it is cyclonic.

From this equation they concluded that the only term which acts to produce vorticity is the last one in the above equation, and in such a way that when there is convergence, cyclonic vorticity increases. This result is quite in accordance with the theory of revolving fluid of Rayleigh,[3] Shaw,[4] and Brunt.[5] Then what is the cause of convergence? In the old convection theory of Ferrel, a low pressure centre of thermic origin is presumed to exist from the beginning and consequently a converging current is produced.

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[1] "Growth and decay of vortical systems."

[2] "Die Grössenordnung der meteorologischen Elemente und ihre räumlichen und zeitlichen Ableitungen," *Veröff. Geophys. Inst. der Universität, Leipzig*, 2te Serie, H. 6, pp. 167, 169.

[3] "On the dynamics of revolving fluids," *Proc. R. Soc.*, **93** (ser. A.), 1917, p. 148.

[4] He has written many papers in this line. See "Manual of Meteorology," Part iv. Recently he had a new idea about the mechanism of convection, but he intends to apply it to tropical cyclones. *Meteor. Off., Geophys. Mem.* No. 19, London, 1922, M.O. 220 i.

[5] "The dynamics of revolving fluid on a rotating earth," *Proc. R. Soc.*, **99** (ser. A), 1921, p. 397.

Modern meteorologists, however, deny the prior existence of a low pressure centre of thermic origin, at least for the extratropical cyclone. Hence we must look for other causes for the convergence of the air current.

Here come many hypotheses in which a sucking action from the upper atmosphere is assumed, which may be caused by a low pressure in the stratosphere. This might be the case, but it is not yet positively proved.

One of the most striking actions to produce a low pressure area, or better to say a low pressure belt, is that of the two counter currents in geostrophic equilibrium. Every atmospheric current under this equilibrium must have a high pressure area on the right-hand side of its course and a low pressure area on its left, in the northern hemisphere, so that there must exist a low pressure belt between two counter currents. This is a well-known fact and well explained in text-books.

Now this belt tempts us to take it as the low pressure area causing the converging air current. But only a little further consideration unveils the circular reasoning in it, because the low pressure area is necessary in order to cancel the deflecting force and hence the barometric gradient produced must balance it.

Suppose then that the original current begins to lose its velocity. Then the pressure gradient overcomes the deflecting force and a converging current will be produced. In this way a whirl with a cyclonic rotation may start, but here the converging current is produced only to fill up the low pressure centre, and thus the whirl produced must have a higher pressure in the centre than was formerly in the belt, so that the pressure must always tend to increase. This is evidently not the actual case, as has already been shown in § 28 of my second paper.

Then one may take thermodynamical action in aid, assuming an ascending current and consequent condensation of water vapour. This theory is not sound, because the converging current is not lighter than the surrounding air, though not heavier; ascending motion cannot be sufficient, and also condensation cannot help the growth of the cyclone, because if it does, it requires the stratification to be already unstable, and the ascending motion might have occurred elsewhere before. Condensation can preserve the cyclone against decay in one way, and the function is to some extent passive.

Then there is a third possibility that at the most northerly point of the warm tongue of the atmospheric current on the south side the barometric pressure must be lowest, and hence the converging current must occur there, by which the deflecting force of the earth's rotation can act to produce a cyclonic vorticity. This theory seems better, but unfortunately the low pressures are threaded on the left-hand side of the warm tongue, as shown by Bigelow[1] and also by J. Bjerknes[2] and others. For this fact we need some action that deflects the current to the left. Here is a difficulty, and indeed such an eminent philosopher as Prof. F. M. Exner[3] thinks the left deflecting force may be due to the frictional action of the earth's surface, and he adds that the analytical proof for it is not yet arrived at.

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[1] Bigelow, F. H., *Mon. Weath. Rev.*, *Washington*, **30**, 1902.

[2] *Geofys. Publ.*, *Kristiana*, **2**, No. 3, Sec. 38.

[3] "Dynamische Meteorologie," pp. 254, 255.

The difficulty is more or less decreased by the discovery of Mr. J. Bjerknes and his colleagues[1] that the germ of a cyclone is produced at the very slight bending of the nearly straight polar front. And in the course of its development the southerly warm current turns round to its east side. Thus we are released from the necessity of explaining the left deflecting tendency, but at the same time the first central deepening is so shallow that it might very soon be filled up without some action to support it. They think with Margules that the thermal potential energy of adjacent air masses can feed the cyclone. This seems to be true, but further explanation is desirable, because the thermal potential energy which will be the food of the cyclone must have existed before, and we want to know why it was not spent before, according to the law of the degradation of the available energy; or in other words, what is the actual mechanism that converts the thermal potential energy of the atmosphere into the kinetic energy of the vortical motion. Here we must find the application of our theory of the animate growth of the vortical motion to explain this mechanism and at the same time perhaps that of the left deflecting force at the earth's surface.

§ 3. *Further Investigation of the Hesselberg-Friedmann Equation.*—Let us now modify the equation in the last section in the following form:

$$\frac{\partial w_z}{\partial t} = -\left(v_x\frac{\partial w_z}{\partial x} + v_y\frac{\partial w_z}{\partial y} + v_z\frac{\partial w_z}{\partial z}\right) + \left(w_x\frac{\partial v_z}{\partial x} + w_y\frac{\partial v_z}{\partial y}\right) - (w_z + \lambda)\left(\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y}\right).$$

This equation gives the variations at a given point instead of those for a given moving mass element. The first term on the right-hand side of the above equation represents the increase of the vorticity due to the heterogeneous distribution of the vertical vorticity in the field concerned. All the eddies which express vorticity being carried by the general current will pass a given spot one after another so far as they are along the same stream line passing the spot considered. At the moment when a stronger vortex comes after a weaker one, then the vorticity at the spot is increasing. The second term means the replacement of horizontal vorticity by vertical vorticity. The third term is the increase due to the convergence of the velocity field. Now w_z and λ have the same order of magnitude, and the former can exceed the latter in a strong cyclone.[2] The convergence in the cyclone is of course greater than that in another place, and has an order of magnitude from 10^{-4} to 10^{-5} sec^{-1}. Thus the order of magnitude of the third term is from 10^{-7} to 10^{-9} sec^{-2}.

Vortices with horizontal axes do not always exist, or at least if they exist they are not intense in ordinary cases, but when there is a surface of discontinuity in the atmosphere they exist with strong intensity. In order to get an idea for them the following cases, which are rather remarkable, are picked out from the *Daily Weather Report* of the Meteorological Office, Upper Air Supplement, for the period from the end of August to that of September 1921:

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[1] Lecture delivered before the Conference of the Commission for the investigation of the higher atmosphere in Bergen, July 25th, 1921.

[2] w_z has the value just double of the angular rotation. In the investigation of the trajectory of Shaw and Lempfert we can see many examples in which w_z has greater value than λ. See "Life-history of the Surface Air Currents." M.O. 174.

No.	Station.	Date.	Hour.	Lower Wind.		Upper Wind.		Difference of Height between.	Vector Difference of Velocity.	$w_h \times 10^3$
				Dir.	Vel.	Dir.	Vel.			
				e.	m/h.	e.	m/h.	feet.	m/h.	sec. $^{-1}$
1	South Farnboro'	31 Aug.	13	195	16	305	17	7,000	27	11·4
2	Cattewater	5 Sept.	13	55	8	195	8	6,000	15	7·4
3	Croydon	15 ,,	7	35	8	245	36	4,000	43	31·6
4	,,	16 ,,	17	60	23	285	14	7,000	34	14·2
5	Valencia	19 ,,	7	280	4	100	20	3,000	24	23·6
6	Lympne	26 ,,	17	205	11	25	22	11,000	33	8·8
7	Cranwell	29 ,,	12	135	7	315	1	2,000	8	11·9
8	Calshot	29 ,,	17	80	20	250	13	5,000	33	19·4

Some of these vorticities have a positive sense of rotation and others negative. Most of them took place at higher level, and direct relation between them and actual cyclones are difficult to find. They were observed when the weather was rather clear, and hence we cannot take them as characteristic of cyclones. When it is stormy observation is difficult. Hence for the present I shall be content with the above figures as the existing horizontal vorticity; we have no reason to suppose that there must not be stronger vorticity in the vicinity of a cyclone than that given by the above-quoted figures.

From the above table we can see that the order of magnitude of the horizontal vorticity w_h is 10^{-1} to 10^{-3} per second for rather remarkable cases. The order of magnitude of the variation of the vertical velocity $\partial v_z/\partial h$ is something like 0·1 m/s per 10 to 100 km. (This may be much greater where the cyclonic activity is vigorous.) Thus the order of magnitude of the second term in the above equation is 10^{-6} to 10^{-9} sec.$^{-2}$. This is more important than the third. This shows that the second term is far more important than the third term for the growth of the cyclone.

Now we shall consider the first term of the equation. As found in § 30 of the second paper, heterogeneity of vorticity nearly always exists in the field of the actual atmospheric motion, and in such a way that on the front side of a cyclone there is generally cyclonic vorticity, and at the rear anticyclonic vorticity. We can use the components of velocity v_x and v_y in this term, sometimes as those of the mean motion and sometimes as those of the vortical one, and the latter way is more interesting than the former. Consider a cyclone with cyclonic and anticyclonic vorticities on its east and west sides respectively. Then on the east and west sides the variation of the vorticity is zero and no increase nor decrease of vorticity occurs in the way mentioned. On the north side there is a negative gradient of vorticity; and velocity is also negative and hence there is increase of vorticity here. On the south side there is a decrease of the vorticity for the same reason. Now in the actual case the heterogeneity is not so regular as supposed above and the vorticity of the field is more localized. The motion of air here is not quite circular but has an inward component in most cases. Thus the increase of vorticity will occur in some segment situated in the leeward of the region where the cyclonic vorticity is a maximum. This is in accordance with the observed fact in § 30 of the last paper. This way of increase is not any increase of the total vorticity when the whole field is concerned, but when there is a possibility of the amalgamation or swallowing action of the cyclone for external vorticity, the above process certainly helps the increase of the intensity of the cyclone. Since the cyclonic vorticity is destroyed by the anticyclonic vorticity at its rear, the displacement of the centre of the cyclone must be caused also in this way.[1] The order of magnitude of this term is very small at the centre of the cyclone when we put the motion of the centre due to the general drifting current out of consideration. Just outside the cyclone it has the value something like 10 m/s multiplied by 10^{-4} sec.$^{-1}$ per 50 to 100 km., *i.e.* the order of magnitude of 10^{-8} to 10^{-7} sec.$^{-2}$.

Thus we can see that in general the effect of the second term in the above equation is the most important, then the first term, and then the third term. These terms have distinct functions, *i.e.* the first term acts to cause the displacement of the cyclonic centre; the third term is powerful at the centre to increase mostly but sometimes to decrease the strength of the cyclone; and the second term performs both these functions. Thus there is no wonder that we have found a marked correlation between the area of the cyclonic vorticity of the field and the region of the falling barometer in connection with cyclones.

On the other hand I examined whether there is any relation between the convergency of the velocity field and falling barometer, but I could not find any in the expected sense, but rather, to my astonishment, the inverse correlation—that is, the converging part of wind, or rather that of the isobars, seems frequently to accompany the rising barometer, and the diverging part the falling.

We shall, however, not enter too much into this new problem now, but close this paragraph by concluding that for the actual forecasting of weather it will be of some use to estimate roughly the value of the terms in the above equation for the purpose of the daily weather service.

§ 4. *The Equation of the Centre of Vorticity.*—The position of the centre of vertical vorticity is expressed in such a way that

$$\bar{x}=\frac{\Sigma\kappa x}{\Sigma\kappa},\ y=\frac{\Sigma\kappa y}{\Sigma\kappa},$$

where κ means the strength of each individual vortical filament, x and y being the co-ordinates of its position.

Differentiating these we get

$$\frac{d\bar{x}}{dt}=\frac{\Sigma\kappa\dot{x}}{\Sigma\kappa}+\frac{\Sigma\dot{\kappa}x}{\Sigma\kappa}-\frac{\Sigma\dot{\kappa}\Sigma\kappa x}{(\Sigma\kappa)^2}.\ \text{etc.}$$

The first term on the right-hand side means the motion of the centre due to the motion of the existing vortical filaments. The drifting action of the general current is therefore contained in this term, and this action is generally the most powerful.

The second term means the motion of the centre due to the increase or the decrease of the vorticity of the filaments, of which we have had some knowledge in the last paragraph.

If we select our co-ordinate origin at the present position of the centre, the third term vanishes.

We must not make confusion between the centre of the cyclone and the centre of the vorticity. But it is very probable that, by confining the field of reference within a suitable limit, the approximate parallelism of the motions of these centres can be established. Hence in this way we can guess the direction and speed of the centre of the cyclone. The calculation of the velocity of a cyclone from the intensity of the gradient wind at its rear is one part of the operation of calculating the first term of the above equation, and therefore is very useful but it is not yet complete.

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[1] H. Jeffreys has also proved the possible motion of an asymmetrical cyclone. See "On travelling atmospheric disturbances," *Phil. Mag.*, 37, 1919, pp. 1–8. See also § 4.

§ 5. *The Function of the Steering Line and Squall Line.*—The second term in the equation of § 3 is the most important one as shown there. Suppose a horizontal vortex roll in the vicinity of a cyclone. By the ascending motion of air in the cyclone, this roll must gradually bend upwards within the cyclonic area. If the sense of rotation of the roll is clockwise facing the cyclone, the part of the roll bent up has the cyclonic sense of rotation and hence it must approach the cyclone and be absorbed into the core of the cyclone. Consequently the remaining part of the roll, which is still horizontal, must be attracted towards the cyclone. On the contrary, if the roll has counter-clockwise rotation, then the bent-up part has anticyclonic rotation and hence must go away from the cyclone. Thus *along such a horizontal vortex roll there is always transmission of vortical energy in the sense of a right-handed screw.*[1] From this we can get an idea of why the warm front, the line of discontinuity which lies at the right-hand boundary of the warm sector of a cyclone, was called the steering line.

Obviously this line is the intersection of the surface of discontinuity in the atmosphere with the surface of the earth, as shown by V. and J. Bjerknes. The former surface must be the seat of the greatest horizontal vorticity, because the velocity of wind above and below this surface has different directions and velocities.[2] In his first paper[3] Mr. J. Bjerknes has shown that along the steering line there is a line of convergence preceded by a line of divergence. These two lines must be the sign of the existence of a horizontal roll of vortex. This roll will gradually tend to become vertical according to the action explained above and also by the limitation of motion at the ground as elucidated in my first paper.[4]

The sense of rotation is that of the right-handed screw facing the cyclone, hence the sign of the second term in the equation of § 3 is positive, which means that cyclonic vorticity will increase. At the central part or central ring of a cyclone the inward gradient of the ascending motion of air is greatest, and hence at the point where the steering line enters the central part the rate of increase of vorticity is greatest and therefore the displacement of the centre towards this direction is most probable, because here is the biggest income of the vortical energy of the cyclone, as explained in the last paragraph. According to W. Schmidt[1] and Shaw[2] the sense of rotation of horizontal vorticity at the squall line is that of the left-handed screw facing the centre of the cyclone. According to the opinion of J. Bjerknes[3] the sense of rotation must be that of a right-handed screw. Both these opinions seem to be correct. Examining actual weather maps we can see that along the squall line there lie two parallel rolls of horizontal vortices of opposite sense of rotation. One with clockwise rotation facing the cyclone is situate rather near to the centre and not strong and decreases its intensity as the distance from the centre increases, while the other with counter-clockwise rotation gradually increases its intensity with distance from the centre. The former roll tends to go in to the centre, while the latter tends to go away from it according to the action described above. We can see the bending of the isobars outwards and the accompanying wind along the squall line at some distance from the cyclone in actual weather maps, showing the existence of the above-mentioned roll of counter-clockwise rotation. Thus the squall line may supply energy to the cyclone, but not so much as the steering line does, while it tends to build up a secondary to the right-hand side to which its vortical energy flows in. So that the squall line cannot be any indication of the movement of the cyclone, but can serve as that of the formation of a secondary. This is quite in accordance with the facts observed by those in Bergen.

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[1] This theorem also holds good for cyclones and anticyclones, though they are vertical whirls.

[2] Dines, L. H. G., kindly suggested that in stable equilibrium of the atmosphere such a horizontal roll cannot exist; if it exists, it soon dies away. Well, this is also seen from the last term of Richardson's equation (see § 13 of my second paper, or *Proc. R. Soc.*, **97** (ser. A.), 19, eq. 5. 2). Along the surface concerned, the term acts to help to form the vortical rolls.

[3] "On the structure of moving cyclones," *Geofys. Publ., Kristiania*, **1**, No. 2, Figs. 1 and 2.

[4] Fujiwhara, S., "The natural tendency towards symmetry, etc.," *Q.J.R. Meteor. Soc.*, **47**, 1921, p. 287.

In the region where the upper current is westerly, the sense of rotation of the horizontal vortices is that of the right-handed screw facing to the north. Hence the cyclonic centre situated to the north of these horizontal vortices can get energy from them, but those centres lying to the south cannot. This must be the reason why steering and squall lines always run towards southerly points from the centre. When the direction of the upper current changes, and the air travels towards the west, then these lines will come from the north to the centre of the cyclone and the westward motion of the centre must be the result. Perhaps somebody can find an actual example of this.

As we can see from the equation of §§ 3 and 4, and also from the fact of amalgamation or swallowing of other whirls, it is clear that there are sources of vortical energy of a cyclone other than that of the horizontal vorticity. Hence it is quite natural that a cyclone sometimes does not follow the way indicated by the steering line. Such a case, however, happens seldom, because the steering line is the most powerful of all the sources of energy in ordinary cases.

When the polar front lies west-east, the horizontal vorticity is not great, and its sense is that of the right-handed screw facing to the west. On account of the vertical vorticity necessarily existing there, or on account of some orographic effect, a small bending of the polar front will be produced. According to the property of a horizontal vortex it must break up at some point, and must tend to become normal to the ground. The above bending will give the chance to the point of break, and the horizontal roll must also bend up at the northern end of the horizontal bending, because there both actions operating to bend up the horizontal column—one due to the effect of the ground, the other due to the variation of ascending velocity expressed in the second term of the equation of § 3—can act together. Since the phenomenon is of an animate character, small whirls of cyclonic rotation, such as are observed in cloud forms, which might happen to be near by, must join to accelerate the above process. Thus a small centre of whirl of cyclonic sense of rotation can be formed, to which energy of vorticity flows mainly along the two horizontal rolls of vortices, whose ends are winding together at the centre. This may be the initial state of an extratropical cyclone. The two rolls also develop in this way, because by bending towards the north they can get energy from the westerly current prevailing above.

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[1] *Wien. Sitzber.*, **119** (2*a*), 1910, p. 1101.

[2] "Forecasting Weather," p. 248.

[3] *Loc. cit.*, Fig. 1, but not 3. He told me personally that his opinion was based upon the observation of C. K. M. Douglas ; I owe very much to Mr. J. Bjerknes.—S. F.

When the rush of cold air at the squall line is strong, getting potential energy due to the difference of densities of warm and cold currents to accelerate its velocity, then the velocity near the earth's surface will exceed that of the upper warm current; thus a left-handed horizontal vortex is formed, and its velocity of advance exceeds that of the upper current. The velocity of the steering line must be equal or less than that of the upper current, hence in this case the squall line must overtake the steering line and the warm sector must be closed up in the cold current. At this state the two rolls of the counter rotation at steering and squall lines must interfere one with the other and destroy their intensity. Thus the cyclone cannot get energy sufficient to maintain itself and will gradually tend to decay. This may be the explanation for the occlusion of a cyclone which was found lately at Bergen.[1]

§ 6. *The Function of the Deflecting Force.*—In the equation in § 3 we have seen that the deflecting force of the earth's rotation plays the rôle of second or third importance for the growth or birth of a cyclone. We know, however, that all cyclones in the northern hemisphere have the anti-clockwise rotation. This shows that the deflecting force has importance in another way. Undoubtedly the geostrophic relation rules the earth's atmosphere on ordinary days, as so concretely worked out by Sir Napier Shaw and his colleagues. Under the geostrophic balance any steady current in the northern hemisphere must have high pressure area on the right-hand side and low pressure area on the left. Hence the low pressure area, thus mechanically produced, always lies between two counter currents and the consequent vorticity must be counter-clockwise. Any cyclone of kinematical origin can develop in such a field of vorticity, taking its nourishment from the surrounding field. Hence these cyclones must have counter-clockwise rotation in the northern hemisphere. The reason why cyclonic circulation is generally more intense than the anticyclonic is given in the next section.

§ 7. *The Rôle played by the Earth's Surface.*—The surface of the earth gives a powerful limitation to the motion in the atmosphere. As seen in the experiment explained in § 6 of the second paper, a solid surface lying at the bottom of a water-mass gives a tendency to a water whirl to have ascending motion at its core. At places remote from boundaries the sense of motion along the axis of a whirl is quite arbitrary. Near the earth's surface the ascending motion seems very easy along the axis of the whirl. The reason for it is not yet quite clear, but perhaps we can explain it in the following way as a trial:

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[1] Bjerknes, V., "On the dynamics of the circular vortex, with applications to the atmosphere and atmospheric vortex and wave motions," *Kristiania, Geofys. Publ.* **2**, 1921, No. 4, sec. 38, p. 80.

There may be two actions due to the existence of a solid bottom surface.

The first action is the simple resistance to the motion, acting just opposite to it. This action is caused by means of horizontal eddies whose axes are perpendicular to the direction of the general motion, and whose sense of rotation is that of the right-handed screw facing to the left of the general motion. By this action under the co-operation of the deflecting force of the earth's rotation the wind direction at some 2 or 3 kilometres above the ground is gradually deflected to the left as the height decreases in the northern hemisphere, as was well worked out first by Guldberg and Mohn and later on by many Scandinavian and British meteorologists.[1] Thus near the earth's surface air comes out from the high pressure area and flows into the low pressure area, which implies a descent in high pressure regions and ascent in low pressure regions in the surface layer.

The second action is concerned with a whirl having a vertical axis. At the bottom of such an atmospheric whirl eddies with horizontal axes of rotation must form on account of the frictional action of the earth's surface. When the whirl is counter-clockwise, the sense of rotation of eddies is that of the right-handed screw facing to the centre of the whirl, and when the whirl is clockwise the eddies have the left-handed rotation. When there exists even a little ascending motion at the core of the whirl it is clear from the second term of the equation of § 3 that these eddies must bend upward near the core and come to have a vertical component of rotation of the same sense as that of the original whirl. According to the animate character of the vortical motion, the whirl absorbs those eddies, because they have the same sense of rotation. Thus the converging and consequently also the ascending motion at the core are accelerated in an animate way. Such action, however, cannot take place when the initial motion at the core is descending, because there is no room for eddies to bend downwards near the core.

I am not yet quite sure whether this second action of the earth's surface is sufficiently powerful or not,[2] but it is certain that *the solid boundary at the bottom gives a tendency to ascending motion along the axes of whirls of both senses of rotation.* The above explanation and fact can hold good for water vortices as well as the atmospheric whirls.

Near the solid bottom, therefore, the stability of the two-dimensional motion pointed out by G. I. Taylor[3] is disturbed, though the orbital or vortical motion always tends to become parallel to that surface. Only in the decaying phase the two-dimensional stability of the revolving fluid may be experienced near the solid surface.

The First and Second Actions combined.—When the original whirl is small and its rotation is quick, the second action must be remarkable, so that the ascending motion can be produced for both senses of rotation at the core of the whirl near the solid bottom. When the whirl is large and its rotation is rather slow and is comparable to that of the earth's rotation, the first action becomes important and it gives direction to the second action how to act. According to the first action ascending motion is easier than descending in the low pressure area, where the vorticity has the counter-clockwise rotation in the northern hemisphere, and descending motion is easier than ascending in the high pressure area as explained above. The converging and ascending motion due to the second action in a whirl in the northern hemisphere is cancelled when it is of clockwise anticyclonic rotation by the diverging motion due to the first action, and is accelerated when it is of cyclonic rotation by the converging motion due to the first. Since the second action has an animate character, the co-operation of both actions results, not in the mere addition of the two, but in a much accelerated state.

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[1] See Chapters I. to IV. of "Manual of Meteorology," Part IV., by Sir Napier Shaw.

[2] We have no direct observation on this point. Estimation of the order of magnitude of this action gives me an idea that this action is rather important.

[3] "Experiments with rotating fluids," *Cambridge, Proc. Phil. Soc.*, **20**, Part 3, p. 326.

§ 8. *The Path of Energy from Thermal to Vortical.*—Max Margules has shown how the thermal energy of air masses can be converted into kinetic energy.[1] He, however, did not reach vortical kinetic energy. We want some explanation for the mechanism which leads thermal energy to vortical energy. If thermal energy can be converted directly into vortical energy, we must have cyclones where the difference of temperature on the polar front is greatest. This is not actually the case as seen in every day's weather maps.

In §§ 3 and 5 we have already got an idea that on the surface of discontinuity between so-called polar and equatorial air there must exist some number of horizontal rolls of vortices of one and the same sense of rotation, and from such rolls a cyclone can get vortical energy. If there is no temperature difference between the two air masses, and they have different velocities, then they cannot run regularly one over the other, and consequently the regular rolls described above cannot develop; turbulence of haphazard nature having various directions and senses of rotation will take its place and will die down very soon in virtue of the stability of the atmosphere.[2] Thus the existence of temperature differences is very important to produce the regular horizontal vortices, along which, as shown before, vortical energy flows into the cyclone and feeds it. Thus Margules's investigation seems to have reached the final goal.

§ 9. *The Growth of a Cyclone.*—We need say little here. It is quite natural that a germ or germs of cyclonic whirls may find their places along the trough line of a low pressure belt, where the cyclonic vorticity is prevailing. Some of them can be under more favourable conditions than the others and will get more strength and will grow in an animate way and will form a small centre or centres, to which the remaining vortices will contribute with all of their strength. Such centres will again unite into one according to the fundamental faculty of the vortical motion, and so on, and will at last build up an active centre, which may perhaps be recognized as a slight bending of the polar front or a very shallow V depression. Such centres can grow in an animate way, taking food from the general vortical field, from the horizontal vorticity at the surface of discontinuity, and so on as explained in the preceding paragraphs. Here the buoyancy of the so-called equatorial air, *i.e.* the warm air from the south—we are talking of the northern hemisphere—certainly may help the ascending motion at the centre, but it is difficult to explain all the phenomena pertaining to the cyclone only by that action of buoyancy; especially difficult to explain the animate growth. This action of buoyancy is limited to the lowest one or two kilometres, as is well known from the temperature distribution in cyclones.

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[1] "Energie der Stürme," *Wien. K. K. Zentralanstalt*, *Jahr.* 1903, *Anhang.* Also in Abbe's "The mechanics of the earth's atmosphere," 3rd collection.

[2] Richardson, L. F., "The supply of energy from and to atmospheric eddies," *Proc. R. Soc.*, **97** (ser. A), 1920, p. 370.

Even when there is no help from buoyancy, a cyclone can grow in so far as there is some source of energy in the form of the general vorticity of the field, because the ascending motion can be produced by the action of the earth's surface.

In this way the ascending motion in the cyclone is mostly forced by the kinematical action, and it is quite natural that above the cyclonic area the lower temperature reigns.

In this way the structure of the travelling cyclone surveyed by J. Bjerknes not only has no contradiction with the famous result found by W. H. Dines[1] that the cyclonic column is cooler than that of the anticyclonic one, but also stands in a very good harmony with it.

The next question which naturally arises is, what is the destination of the uplifted air mass in the cyclonic area? It can find its settling place only in an anticyclonic region. Sir Napier Shaw has already discussed this.[2]

§ 10. *Travelling Anticyclones.*—Here we must discuss first the reason why anticyclonic circulation with diverging motion near the ground cannot be accelerated in the same way as cyclonic circulation.

Really the third term in the equation of § 3 shows us that the anticyclonic whirl can be accelerated by the deflecting force of the earth's rotation and also by its own vorticity where there is horizontal divergence in the field, which condition is quite well satisfied in the anticyclone. There is also horizontal vorticity, and also there may be the horizontal variation of the descending motion to give energy to the anticyclonic whirls in virtue of the second term of the equations of § 3. There is also heterogeneity of anticyclonic vorticity in the actual atmosphere as already shown in § 30 of the second paper, hence the equation of animate growth of § 3 seems to be applicable for the anticyclone. But the case is almost the contrary; anticyclones are not so intense as cyclones, though they have greater area and some intrinsic power. What is the reason for this? The only cause which seems sufficiently powerful is that the diverging whirl lacks the faculty to take in other whirls or vorticity with which it can feed itself.

The action of the earth's surface is to produce an ascending current for both the clockwise and anti-clockwise whirls. Hence this helps the cyclonic circulation and prevents the anticyclonic one. At the bottom of this action, however, the above-mentioned fundamental property of the animate growth of vortical motion lies, hence this is not an essentially different action from the former one.

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[1] Mr. W. H. Dines told me that Teisserenc de Bort may have been the first who noticed this. Anyhow, nobody doubts that the fact is confirmed by Mr. Dines.

[2] Structure of atmosphere up to 20 km., "The Air and its Ways" (Cambridge University Press), 1923. Geophysical Memoir, No. 19, § 15: "General Settlement in Anticyclone" (Meteorological Office, London), 1922.

Moreover, in order to keep balance with the neighbouring cyclones—that is, to afford sufficient drainage to the forced-up air in the cyclonic region—an anticyclone must have a larger area in so far as its descending motion is small compared with the ascending one in the cyclone. This, however, is convenient in avoiding the preventive action of the earth surface against the descending motion; because in this way the horizontal variation of the descending velocity is sufficiently small, and consequently the second term in the equation of § 3 cannot be powerful, and hence the action of the ground is not strong. For the same reason the anticyclone cannot take sufficient energy from horizontal vorticity though the latter is existing in the field. This accounts for the want of steering or squall lines in anticyclones.

Thus the only action which supports the anticyclonic circulation is the third term in the equation of § 3, and we can thus understand that the anticyclonic circulation is not zero but rather weak. When the vorticity of the field is very strong the anticyclonic whirl can be produced with ascending motion at its core and converging motion near the ground. In this case the dimension must be small to give sufficient power to the second action of the ground and the second term of the equation of § 3. In the free atmosphere it seems more easy for the existence of clockwise whirls than near the ground.

§ 11. *Buoyancy and Eviction.*—The result derived from the theory of the late Lord Rayleigh, that the action of drawing the air from the core is sufficient to maintain a whirl, assuming the existence of a general vortical field, is the same thing as that shown by the third term of the equation of § 3, because the convergence is the direct and necessary result of drawing air from the core. This is quite an important action as observed before. The buoyancy of warm and moistened air can perform the above action of drawing air upward, as shown by Sir Napier Shaw in his recent work.[1] The eviction associated with this is the direct result of vortical motion following the demand of the principle of equalization.

We can easily see that the greater the horizontal variation of the density of air the more powerful is this action. Hence the phenomenon belonging to this action, *i.e.* convection, is more remarkable when it takes place in a small horizontal dimension. This is the reason why we have much opportunity to observe the phenomena in the formation of cumulus and in local thermal thunder-showers, which are generally multiple and distributed spasmodically.

In consequence of the horizontal convergence resulting from the ascending motion of the convection, the whirl motion of the cyclonic sense must follow, as explained before. I observed cumulus many times making revolutional motion, though it is apparently very slow.

Just as the small bending on the polar front of J. Bjerknes, such a small vortical motion can grow in an animate way, making something like the struggle for existence, to form a germ or germs of a cyclone. It is generally known that the birth of a tropical cyclone is preceded by many local showers and thunderstorms. Perhaps this may be one of the important causes of the tropical cyclone, for whose growth a general vortical field and horizontal vorticity must, of course, be necessary to supply direct food to it. Here I cannot enter into this problem further, and leave it to somebody else.

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[1] *Loc. cit.*, Geophys. Mem. No. 19.

§ 12. *Proposal for forecasting Weather.*—I wish to propose to those who are studying the art of forecasting weather to calculate the vorticity and convergence—divergence contained in algebraic sense—on the weather chart. In order to get the vorticity, we can calculate the circulation along the boundary of the region concerned. These operations can be easily done by making use of the celluloid scale for gradient wind.

In conclusion, I wish to express my best thanks to Sir Napier Shaw and to J. Bjerknes for their kind guidance and advice.

Note.—In a letter dated 23rd May 1922, the author refers to a paper on vortices by Fr. Ahrborn in the *Physikalische Zeitschrift*, Nr. 3, 23 Jahrgang (1922 Feb.).

DISCUSSION.

The President (Dr. C. **Chree**) referred to the difficult mathematics, and remarked that the heavy cost of printing such a paper at present could only be justified by regarding it, as the Society's experts did, as a very exceptional piece of work.

Mr. L. F. **Richardson** said that Dr. Fujiwhara had calculated the rate at which energy was being transferred from the mean motion of an eddy of one "generation" to the motion of the eddies of the next lower "generation" contained within the larger eddy. Dr. Fujiwhara had used for this purpose a part of a formula attributed to the speaker, a part really due to Osborne Reynolds. This important part showed the activity in question as the product of an eddy-stress into a rate-of-mean-shear. The notion of eddy-stress was usually associated with the presence of eddies in large numbers. Was it a fact that in the atmosphere eddies occurred in distinctly separated sizes, each "generation" containing within it very many of the next lower "generation"? Dr. Fujiwhara's photographs for water did not suggest this. Again, with regard to the rate-of-mean-shear of the "parent" eddy, the paper was not clear as to how this quantity was related to the kinetic energy of that eddy as a whole. For instance, Sir Napier Shaw ("Manual," Part IV.) had described a storm at Southport in which the revolving air went round as if it were rigid—that is to say, without shear. The papers were certainly full of novel ideas.

Sir **Napier Shaw** said he would gladly be personally responsible for the paper. Even if the mathematics were incorrect, which was not likely, it was a most valuable contribution to meteorological thought on the subject. It would make people think about the subject of eddies, and so do some thinking that they had never done before. He hoped it would be correct thinking, and if incorrect there were people present who would substitute the correct way of thinking. He had seen the paper grow, and there was much new thought in it. Nobody could read it without being convinced that there is a great deal in the atmosphere that they had not thought of before. Utilising the energy of the rudimentary vortices due to shear between successive layers in order to maintain a cyclone seemed to be a line of thought worthy of consideration. The whole of the atmosphere must be full of vortical motion. If it is possible for the energy of vortical motion to be collected together in a single vortex we get something of the utmost value. It is particularly important to account for the growth of the energy of a cyclone. He had recently attempted, making certain assumptions, to calculate the energy of a paltry little cyclone in the Mediterranean, and the surprising result was a million horse-power working for fifty years. A large cyclone in the Atlantic had an energy equivalent to a million horse-power working for 5000 years. He went on to calculate what this was equivalent to in rainfall, and it came out as 1 mm. of rainfall over the area covered by the cyclone. Such a transformation might easily happen in one night, so that the machinery for transforming energy must be very interesting if we could understand it.

Dr. G. C. SIMPSON wished to add his thanks to Captain Brunt for bringing this paper before the Society. The mathematics were abstruse, but if the mathematics were left out the paper would still be very valuable. Dr. Fujiwhara had made some interesting deductions and some still more interesting observations. All the mathematics had done was to put the observations into mathematical form, and they did not lead to any new conclusions. The paper is physical and experimental, because the whole question of the mathematics of vortices is much too difficult for practical application. In the atmosphere an ordinary wind-current moving in a definite direction is full of vortices, but he had not previously heard it suggested that these vortices began to absorb one another until gradually a very big one was developed. He understood that Dr. Fujiwhara imagines that a big cyclone forms in a region with a lot of little vortices and absorbs those of the right sign, and grows as a result. He could not see, if this is so, how the cyclone is going to get any more energy than that formerly existing in the air in which it forms. We know that the actual energy in a cubic kilometre of a cyclone is greater than the average energy in a cubic kilometre of the atmosphere. The curves in Fig. 5, which show the growth and decay curves of cyclones, are merely the curves which must be formed by anything which grows and decays; they are not at all convincing.

Col. E. GOLD referred to the statement (3rd memoir, § 10) that "anticyclones are not so intense as cyclones, though they have greater area and some intrinsic power. What is the reason for this? The only cause which seems sufficiently powerful is that the diverging whirl lacks the faculty to take in other whirls or vorticity with which it can feed itself," and asked whether this merely meant that the rotation in the anticyclone is in the opposite direction to the earth's rotation.

Captain D. BRUNT said, with regard to Mr. Richardson's question as to vortices of different sizes, that he had been looking at some photographs of clouds of smoke emitted from a fixed point, and also at trails of smoke from factory chimneys, and found definite evidence in favour of the existence of vortices of widely different sizes, with apparently no vortices of intermediate size. The criticism made by Dr. Simpson about a very large number of small vortices uniting to form a cyclone is not quite in accordance with Dr. Fujiwhara's conception. He assumes the existence of a predominating centre which is able to draw partly on the energy of the earth's rotation, and so becomes powerful enough to absorb the other vortices near it. The results of laboratory experiments are in agreement with those observed at the boundaries of fresh and salt water. Replying to Colonel Gold's query concerning the anticyclone (last paper, § 10), Captain Brunt pointed out that Dr. Fujiwhara's necessary condition for the absorption of one vortex by another is that there should be convergence to the centre, and this is absent in the anticyclone. Also in Hesselberg and Friedmann's equation § 3, the quantity w_z is negative in an anticyclone, so that the factor $w_z + \lambda$ is less in an anticyclone than in a cyclone.

REPORT OF THE COUNCIL

FOR THE YEAR 1922.

[Submitted to the Annual General Meeting, January 17, 1923.]

The history of the Society during the last few years has been eventful. The amalgamation with the Scottish Meteorological Society and the acquisition by the Society of a house of its own were recorded in the last Report of the Council. An event of like importance, which has taken place during 1922, now comes to be chronicled.

As most Fellows are probably aware, the British Rainfall Organization was taken over by Government and incorporated in the Meteorological Office in July 1919. The Trustees of the Organization retained, however, control of the Endowment Fund and the lease of 62 Camden Square, the house where Mr. Symons and his successors had worked since 1859. This remained the home of the Organization until March 1922, when the staff and the records were transferred to the Meteorological Office at South Kensington, while the tenancy of the premises, which H.M. Office of Works, acting for the Meteorological Office, had held from the Trustees, was terminated.

Early in 1922 the Council received an offer from the Trustees of the Organization to transfer their remaining property to the Society, the sole conditions attaching to the transfer being that the Society should agree "to use its best endeavours to continue . . . at 62 Camden Square . . . the observations of rainfall and other meteorological observations which have been carried on there for about 60 years so as to avoid so far as may reasonably be possible any break in the continuity of such observations especially as regards rainfall and evaporation. Upon the expiration of the . . . lease . . . which has at the present time about 22 years unexpired to use its best endeavours to obtain a renewal of the lease . . . or in the alternative to purchase the freehold . . . if a renewed lease or the freehold can in the opinion of the Society be obtained on reasonable terms and if in the like opinion the situation is still suitable for the carrying on of meteorological observations. To apply the Endowment Fund (including the proceeds of sale of the said premises should the same be sold) and the income arising from the Fund and the said proceeds and the rent received in respect of any letting of the premises . . . in the first place in the maintenance of the rainfall and other observations at No. 62 Camden Square and in the next place to the encouragement of voluntary observers of rainfall by every practicable means including for example the loan of instruments and the awarding of certificates or medals for long and accurate records and for the encouragement of original researches into the distribution of the rainfall in any part of Great Britain or into the variation of rainfall in time at any place in Great Britain and generally to the promotion of the study of rainfall either as a meteorological phenomenon or in relation to climatology agriculture water supply water power or other applications. Any part of the Endowment Fund representing income from investments and rent of the said premises and not immediately required for any of the purposes aforesaid may be accumulated and the accumulations resorted to from time to time for those purposes. Not so long as the situation of the premises is suitable for the carrying on of meteorological observations to grant any Lease or Tenancy Agreement of the said premises No. 62 Camden Square or any part thereof on any terms which will or may have the effect of preventing the proper carrying on of such observations and if and whenever the said house shall be let otherwise than in connection with the carrying on of meteorological observations in every such letting to except the garden of the said premises or so much thereof as may be necessary or desirable for the carrying on of the said observations and for this purpose effectively to rail or fence off the said garden so excepted from the portion of the premises to be let and in any letting to reserve unrestricted right of access through the front garden to the garden to be excepted from the letting by the passage lying to the west of the house. To carry out all meteorological observations on the said premises in accordance with the regulations for the time being of the Meteorological Office or other Government Department which may succeed such Office and to be regularly forwarded to that Office or Department for the purpose of being published. To save harmless and keep indemnified the Trustees from and against all claims and demands in respect of the Endowment Fund and every part thereof."

The Council has, in accordance with the conditions of its trust, accepted an offer from the Headmistress of the North London Collegiate School for the observations to be taken by the senior pupils under supervision, arrangements being made to avoid interruption of the observations during holidays. The Society is indebted to Mr. Carle Salter for kindly consenting to supervise the observations. It is also indebted to the Meteorological Office and to Messrs. Negretti & Zambra for the loan of the necessary instruments.

A suitable tenant has been found for the house, and the terms of his agreement provide that he shall be responsible for the upkeep of the enclosed part of the garden containing the instruments, and that the Society's representatives shall have free access.

Amongst the records of the Rainfall Organization there were comparative temperature results from a Glaisher and a Stevenson screen for a number of years. The Council has accepted an offer from Mr. I. D. Margary to discuss these, the Meteorological Office having undertaken to place the records at the disposal of the Society for this purpose.

HOUSING.—At the date of last year's Report the removal of the Society to its new rooms had been accomplished. Certain liabilities, however, had not been settled, so a complete statement of the expenditure involved could not be presented. The account has now been completed, and shows a total expenditure, including the purchase of the house, of £7638. Of this amount £6400 was raised by debentures, while Stock realising £1026 : 10 : 7 has been sold from the New Premises Fund. The sum of £964 South Australian 3½ per cent inscribed stock remains in the New Premises Fund for the present, and will be available for the redemption of debentures.

FINANCE.—The financial position of the Society continues to cause anxiety. To have kept the expenditure during the past year within the income would have entailed a serious curtailment of the Society's activities. The cost of printing was beginning to fall at the end of 1921, and it was hoped that the fall would be progressive, leading to a substantial reduction in the cost of the Journal, which is one of the largest sources of expenditure. This hope has unfortunately not been realised. The cost of the four numbers paid for in 1922 has been £779, as compared with £752 in 1921. Unless the income of the Society can be materially increased in the immediate future, the size of the Journal must be drastically reduced.

If every Fellow would make it his business during 1923, if opportunity offers, to secure one new member for the Society, the necessity for curtailing its usefulness would be avoided.

The Council are greatly indebted to Mr. C. J. P. Cave for the return of one debenture of £50, which he very kindly forwarded for cancellation.

FELLOWS.—Particulars as to the number of Fellows are given in the following table:

FELLOWS.	ANNUAL.	LIFE.	HONORARY.	TOTAL.
December 31, 1921 .	**693**	**199**	**12**	**904**
Since elected . . .	+31	...	...	+31
Reinstated	+ 5	...	...	+ 5
Deceased	−16	−6	...	−22
Resigned, etc. . . .	−58	...	...	−58
December 31, 1922 .	**655**	**193**	**12**	**860**

There is thus a decrease of 44 in the course of the year, attributable to the general financial stringency.

The 22 deceased Fellows, whose loss the Council deeply regrets, included Dr. H. N. Dickson, President of the Society during the years 1911 and 1912, and Dr. C. G. Knott, who was President of the Scottish Meteorological Society at the time of its amalgamation. The complete obituary list is as follows, the dates in parenthesis representing the years of election:

Sir Charles Adam (Scottish Fellow).
H. B. Adames (1912).
H. J. Bailey (1907).
Sir W. H. M. Christie (1882).
Sir T. Glen Coats (Scottish Fellow).
P. A. Cobbold (1908).
C. Cook (Scottish Fellow).
Dr. H. N. Dickson (1887).
H. D. Gardner (1900).
Rev. G. S. Hitchcock, D.D. (1921).
W. L. Jordan (1897).
Dr. C. G. Knott (Scottish Fellow).
J. M. M'Connel (Scottish Fellow).
Mrs. Wilson Pease (1917).
L. S. Priestley (1921).
L. K. Ram (1914).
G. Thomson (1919).
J. R. Tustin (1900).
S. Walker (1888).
B. I. Whitaker (1881).
Capt. H. Williams (1908).
C. L. Wragge (1879).

(*For Continuation of Report of the Council see page* 128.)

APPENDIX

STATEMENT OF RECEIPTS AND PAYMENTS

RECEIPTS.

Balance from 1921—Cash at Bank of England	£24	10	9			
Deposit at London County, Westminster, and Parr's Bank	200	0	0			
				£224	10	9
Subscriptions for 1922	£1449	11	7			
Do. for former years	106	5	6			
Do. for 1923	26	5	0			
				1582	2	1
Life Compositions				10	0	0
Entrance Fees				29	8	0
Dividends and Interest (including £31 : 5 : 3 from invested funds of Scottish Society)				168	18	11
Sale of Publications, Advertisements, etc.				210	18	8
Donation to General Fund—E. Sifontes				2	2	0
Rent of Maisonette (£225, *less* Income Tax £38 : 2 : 5, recoverable)				186	17	7
				£2414	18	0

I.

FOR THE YEAR ENDING DECEMBER 31, 1922.

PAYMENTS.

Journal, etc.—						
Quarterly Journal, Nos. 200-203	£671	1	0			
Illustrations	48	11	1			
Reprints of Papers	52	7	0			
Reviews	7	3	6			
Bibliography of Meteorological Literature, Nos. 1-2	86	11	0			
Monthly Weather Reports, 1921	45	18	9			
Do. part 1920, Scottish Society	7	2	1			
Weather over Scotland, 1918, Scottish Society	10	6	1			
				£929	0	6
Printing, etc.—						
General Printing	£59	14	0			
Stationery	37	13	7			
Books and Bookbinding	23	16	4			
				121	3	11
Office Expenses, etc.—						
Salaries and Insurance	£647	7	9			
Preparation of Bibliography	25	0	0			
Postage	124	0	2			
Telephone Charges	10	4	1			
Auditing Accounts for 1921	9	9	0			
Petty Expenses	18	16	7			
Conjoint Board of Scientific Societies	5	5	0			
				840	2	7
Coals, Lighting, etc.—						
Coal and Coke	£23	17	10			
Lighting (*less* return of £5 deposit fee for electric light installation)	5	12	0			
Water rate	6	9	3			
Insurance	16	7	6			
Furniture and Repairs	15	8	7			
Debenture Interest	383	12	2			
				451	7	4
Meetings—						
Meeting Expenses, Refreshments, etc.	£28	18	8			
Lecture	10	10	0			
				39	8	8
New Premises—						
Grant from General Fund				4	0	11
Balance—						
Cash at Bank of England				29	14	1
				£2414	18	0

Examined, compared with vouchers, and found correct.

BALL, BAKER, CORNISH & CO.,
Chartered Accountants.

FINSBURY COURT, FINSBURY PAVEMENT,
LONDON, E.C.2, *January* 10*th*, 1923.

APPENDIX

ASSETS AND LIABILITIES,

LIABILITIES.

Subscriptions paid in advance	£26	5	0			
Coals and Electric Light	4	13	4			
Quarterly Journal, No. 204	225	13	6			
Monthly Weather Reports, 1922, estimated at	25	0	0	£281	11	10

6 % Debentures.

Authorised.—160 Debentures of £50 each charged on all the property of the Society, both present and future	£8000	0	0			
Issued as at 31st December 1921.—127 Debentures	6350	0	0			
Less 1 Debenture, cancelled during year	50	0	0	6,300	0	0
Excess of Assets over Liabilities[1]				4,497	10	6
				£11,079	2	4

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[1] This excess is exclusive of the value of the Library and stock of Publications, and also of the value of the Securities held on account of the New Premises Fund, estimated on December 31, 1922, at £766 : 14 : 9.

NEW PREMISES FUND,

RECEIPTS.

Balance from 1921—Cash at Bank of England	£200	9	5
Dividends on Investments	62	8	0
Sale of Investments	1026	10	7
Grant from General Fund	4	0	11
	£1293	8	11

I.—continued.

DECEMBER 31, 1922.

ASSETS.

Great Central Railway 4½ per cent Debenture Stock, £800 at 91½	£732	0	0			
New South Wales 4 per cent Inscribed Stock, 1933, £800 at 87½	700	0	0			
Victoria 3½ per cent Loan, 1921–26, £300 at 95½	286	10	0			
London & North-Western Railway Consolidated Stock, £400 at 106¼	425	0	0			
London & North-Western Railway Consolidated 4 per cent Preference Stock, £112 at 79½	89	0	9			
Annuities, 2½ per cent, £231 : 11 : 9 at 53½	123	18	0			
War Stock, 5 per cent, 1929–47, £105 : 5 : 3 at 99 15/16	105	3	11			
Funding Stock, 4 per cent, 1960–1990, £200 at 85¾	171	10	0			
East Indian Railway 4½ per cent Irredeemable Debenture Stock, £500 at 79¼	396	5	0			
				£3,029	7	8

Note.—The above Stock are valued at prices estimated by the Society's Broker.

Subscriptions unpaid, amounting to £333, estimated at	£50	0	0			
Entrance Fees unpaid	10	10	0			
Interest due on Stock, estimated at	14	0	0			
				74	10	0
Furniture, Fittings, etc.	£248	15	0			
Instruments	58	15	7			
Expenditure on New Premises to date	7,638	0	0			
				7,945	10	7
Cash at Bank of England				29	14	1
				£11,079	2	4

Examined, and Securities seen.

BALL, BAKER, CORNISH & CO.,
Chartered Accountants.

January 10*th*, 1923.

DECEMBER 31, 1922.

PAYMENTS.

Balance of a/c for decorations and repairs, Mr. S. Reeve	£1284	10	5
Balance of a/c for removal and dusting of Library	8	18	6
	£1293	8	11

Note.—The Society holds on account of this Fund £964 : 9s. South Australian 3½ per cent Inscribed Stock, 1939.

Examined and found correct.

BALL, BAKER, CORNISH & CO.,
Chartered Accountants.

January 10*th*, 1923.

APPENDIX

BRITISH RAINFALL ORGANIZATION FUND,

RECEIPTS.

Cash Balance transferred	£109	4	2
Dividends on Investments	59	8	7
Payment in lieu of dilapidations received from H.M. Office of Works	50	0	0
Rent of 62 Camden Square (£44 *less* £16 : 11 : 11 Income Tax, Schedule A)	27	8	1
	£246	0	10

RESEARCH FUND,

RECEIPTS.

Balance, January 1, 1922—Cash at Bank of England	£32	11	4
Dividends and Interest	10	0	4
	£42	11	8

SYMONS MEMORIAL FUND,

RECEIPTS.

Balance from 1921—Cash at Bank of England	£51	3	11
Interest received on Investments	24	0	6
	£75	4	5

I.—continued.

DECEMBER 31, 1922.

PAYMENTS.

	£	s.	d.
Repairs and Decorations, 62 Camden Square	£128	2	0
Stevenson Screen and Sundries	8	15	1
Tenancy Agreement	6	0	0
Ground Rent	2	5	0
Balance—Cash at Bank of England	100	18	9
	£246	0	10

Note.—The Society holds on account of this Fund £2151 : 11 : 3 North British Railway 3 per cent Debenture Stock ; £123 : 5 : 0 New South Wales 3 per cent Inscribed Stock ; £100 5 per cent War Stock, 1929–1947 ; £100 5 per cent National War Bonds, 1927 ; and £50 5 per cent National War Bonds, 1928.

Examined and found correct.

BALL, BAKER, CORNISH & CO.
Chartered Accountants.

January 10*th*, 1923.

DECEMBER 31, 1922.

PAYMENTS.

	£	s.	d.
£34 : 17 : 3 5 per cent War Stock, 1929–1947	£33	2	0
Balance, December 31, 1922—Cash at Bank of England	9	9	8
	£42	11	8

Note.—The Society holds on account of this Fund £85 : 9 : 1 Consols, and £157 : 15 : 11 5 per cent War Stock, 1929–1947.

Examined and found correct.

BALL, BAKER, CORNISH & CO.,
Chartered Accountants.

January 10*th*, 1923.

DECEMBER 31, 1922.

PAYMENTS.

	£	s.	d.
Gold Medal, 1922	£30	10	0
Balance—Cash at Bank of England	44	14	5
	£75	4	5

Note.—The Society holds on account of this Fund £700 Cardiff Corporation Redeemable Stock, 3 per cent, and £50 Registered 5 per cent National War Bonds, 1928.

Examined and found correct.

BALL, BAKER, CORNISH & CO.,
Chartered Accountants.

January 10*th*, 1923.

MEETINGS.—In addition to the usual eight meetings, two special meetings were held during the summer, one early in July at Croydon Aerodrome, the other towards the end of July in Edinburgh. The meeting at Croydon was not favoured by the weather, rain setting in early in the afternoon and continuing without intermission. Notwithstanding the rain, Fellows and their friends attended to the number of about 140, and by the courtesy of the Air Ministry were shown the work of the Aerodrome. A considerable number availed themselves of the opportunity to take short flights.

The meeting in Edinburgh formed one of a series which it is proposed to hold from time to time in Scotland. By the kind permission of the Royal Society of Edinburgh the meeting was held in the Society's rooms. It afforded an opportunity for the Scottish Fellows, a good many of whom attended, to make the acquaintance of the representatives from the South, who included the President and Mr. J. S. Dines. In addition to papers, there was an exhibition of meteorological instruments, in which the leading instrument-makers co-operated.

PUBLICATIONS.—*Quarterly Journal.* The four numbers of the 1922 Journal extend to 380 pages, as compared with 306 in 1921, and 462 in 1920.

Bibliography.—Two numbers of this publication have been issued during the year. Publications received from September 1920 to June 1921 were dealt with in the first number, those received from July to December 1921 in the second.

The *Monthly Weather Report* of the Meteorological Office has been distributed regularly throughout the year to such Fellows as desire to receive it.

Phenological Report.—The Report for 1921 was presented at the meeting held on June 21, 1922. The Council are much indebted to Mr. J. Edmund Clark and the late Mr. H. B. Adames for the preparation of this Report, and welcome the valuable assistance given by Mr. I. D. Margary.

LIBRARY.—280 volumes and 250 pamphlets and charts have been added to the Library during the year.

A rearrangement of the Library, consequent on its removal to the new house, is still in progress.

BEQUESTS AND DONATIONS.—Reference should be made to the receipt of four volumes containing a meteorological diary kept by the late Mr. H. E. Blyth at Burnham, Norfolk, from 1840 to 1880. The volumes were forwarded by Mr. A. W. Preston of Norwich. A summary of the temperature and rainfall data contained in the register was published in the July Journal.

HOWARD MEDAL.—The field from which candidates for this medal are drawn has been widened by adding to the "Worcester" the training-ship "Conway" and the Nautical College, Pangbourne, the authorities of these institutions having been found favourable to the idea. The first medal to be awarded on the new basis will be that for 1923. The subject chosen for the essay is "Tropical Storms."

Hints to Meteorological Observers.—The last edition of Marriott's "Hints to Meteorological Observers" has been out of print for some time. In response to several urgent inquiries for a new edition, it was decided to proceed with the revision. Mr. R. Corless kindly undertook the work, and good progress has been made, so that it is hoped the new issue will be ready during the first half of 1923.

Fellows' Room.—The Council have under consideration the fitting up of one of the rooms of the Society's house as a room in which Fellows who desire to consult the Library or to meet their friends can do so in comfort. It is hoped that such a convenience will be appreciated and will add materially to the use of the building.

APPENDIX II.

DONORS TO THE LIBRARY DURING THE YEAR 1922.

1. Institutions.

Azores, Serviçio Météorologique.

Barbados, Colonial Secretary's Office.
Barcelona, Servei Meteorologic de Catalunya.
Batavia, Royal Magnetical and Meteorological Observatory.
Bathurst, Gambia Government.
Beira, Observatorio Meteorologico.
Berkeley, University of California.
Berlin, Deutsche Meteorologische Gesellschaft.
Berlin, Preussische Meteorologische Institut.
Bologna, Consiglio Superiore delle Acque.
Bombay and Alibag Observatory.
Brussels, Académie Royale de Belgique.
Brussels, Ministère des Colonies.
Brussels, Société Belge d'Astronomie.
Bucharest, Institutul Meteorologic Central al Romaniei.
Buenos Aires, Oficina Meteorológica Argentina.

Cairo, Physical Service.
Calcutta, Indian Meteorological Department.
Cambridge, Mass., Harvard College Observatory.
Cambridge, Philosophical Society.
Cambridge, University Press.
Cape Town, Royal Society of South Africa.
Cardiff, Naturalists' Society.
Carlsruhe, Badische Landeswetterwarte.
Cashel, Irish Rainfall Association.
Christiania, Geophysical Commission.
Christiania, Norsk Meteorologisk Institut.
Cienfuegos, Observatorio de Montserrat.
Colombo Observatory.
Copenhagen, Conseil Permanent International pour l'Exploration de la Mer.
Copenhagen, Dansk Meteorologisk Institut.
Cordoba, Academia Nacional de Sciencias.
Coventry, City Medical Department.
Croydon Natural History and Scientific Society.

Darmstadt, Landesamt für Wetter- und Gewässerkunde.
Dublin, General Register Office.
Dublin, Royal Irish Academy.
Dublin, Royal Society.

Eastbourne, City Medical Department.
Easton, Pa., American Meteorological Society.
Edinburgh, Challenger Office.
Edinburgh, General Register Office.
Edinburgh, Royal Scottish Geographical Society.
Edinburgh, Royal Society.
Elisabethville, Vice-Gouvernement Général de Katanga.

Felstead School, Scientific Society.
Florence, Osservatorio Ximeniano.

Geneva, Observatoire.
Geneva, Société de Géographie.
Genoa, R. Istituto Idrografico.
Glasgow, Royal Philosophical Society.
Greenwich, Royal Observatory.
Grenada, Colonial Secretary's Office.
Guernsey, States Meteorological Station.

Halifax, Nova Scotia Institute of Science.
Hamburg, Deutsche Seewarte.
Hankow, Griffith John College.
Havana, Observatorio del Colegio de Belen.
Havana, Secretaria de Agricultura, Comercio y Trabajo, República de Cuba.
Hongkong, Royal Observatory.

Innsbruck, Meteorologisches Observatorium der Universität.

Jamaica, Government Meteorologist.

Kôbe, Imperial Marine Observatory.

Leicester, Literary and Philosophical Society.
Leipzig, Geophysikalische Institut der Universität.
Lisbon, Observatorio Central Meteorologico.
Lisbon, Sociedad de Geographia.
Liverpool, Engineering Society.
Liverpool, Literary and Philosophical Society.
London, Admiralty, Hydrographic Department.
London, Advisory Committee for Aeronautics.
London, Air Ministry, Meteorological Office.
London, Board of Education.
London, British Association for the Advancement of Science.
London, Geological Society.
London, Geological Survey.
London, Institution of Electrical Engineers.
London, Institution of Sanitary Engineers.
London, Institution of Water Engineers.
London, Physical Society.
London, Royal Aeronautical Society.
London, Royal Agricultural Society.
London, Royal Astronomical Society.
London, Royal Botanic Society.
London, Royal Geographical Society.
London, Royal Institution of Great Britain.
London, Royal Sanitary Institute.
London, Royal Society.
London, Royal Society of Arts.
London, Royal Statistical Society.
London Wireless Press.
Lourenço Marques, Serviços de Marinha.

Madrid, Instituto Geografico y Estadistico.
Madrid, Real Sociedad Geográfica.
Manchester Literary and Philosophical Society.
Manila, Weather Bureau.
Marlborough College Natural History Society.
Marseille, Commission de Météorologie du Département des Bouches-du-Rhône.
Mauritius, Royal Alfred Observatory.
Melbourne, Commonwealth Weather Bureau.
Mexico, Observatorio Astronomico Nacional de Tacubaya.
Mexico, Sociedad Cientifica Antonio Alzate.
Mizusawa, International Latitude Observatory.
Modena, Società Sismologica Italiana.
Munich, Bayerische Landeswetterwarte.

Nairobi, Department of Agriculture.
Naples, R. Osservatorio di Capodimonte.
New York, American Geographical Society.
New York, Central Park Observatory.
Nicosia, Cyprus, Public Works Department.
Nottingham City Council.

Ottawa, Dominion Observatory.
Ottawa, Royal Society of Canada.
Oxford, Clarendon Press.
Oxford, Radcliffe Observatory.
Oxford, University Press.

Pahang, F.M.S. Administration.
Panama, Isthmian Canal Commission.
Paris, Observatoire Municipal de Montsouris.
Paris, Office National Météorologique de France.
Paris, Société de Géographie.
Paris, Société Météorologique de France.
Perth, Western Australia, Government Statistician's Office.
Philadelphia, American Philosophical Society.
Port-au-Prince, Observatoire Météorologique.
Porto Alegre, Instituto Astronomico e Meteorologico.
Portsmouth Medical Department.
Prague, Institut Central Météorologique de la République Czecho-Slovakia.

Reykjavik, Section Météorologique de Löggildingarstofan.
Rhodesia, Southern, Agricultural Dept.
Rio de Janeiro, Directorio de Meteorologia.
Rio de Janeiro, Observatorio Nacional.
Rome, International Institute of Agriculture.
Rome, Ministero dei Lavori Pubblici.
Rome, Reale Società Geografica Italiana.
Rome, Ufficio Centrale Meteorologico e Geodinamico.
Rome, Union Internationale de Géodésique et de Géophysique.
Rothamsted, Experimental Station.

St. Lucia, Government Office.
San Fernando, Institute y Observatorio de Marina.
San Juan, Porto Rico, W. Indian and Caribbean Service.
Simla, Meteorological Office.
Southport, Fernley Observatory.
Stockholm, Hydrografiska Byrån.
Stockholm, Statens Meteorologisk-Hydrografiska Anstalt.
Stonyhurst, College Observatory.
Strasbourg, Institut de Physique du Globe.
Subiaco, Observatorio di Montecassino.
Sucre, Bolivia, Observatorio Meteorologico.

Teddington, National Physical Laboratory.
Tokyo, Central Meteorological Observatory.
Tokyo, Imperial Earthquake Investigation Committee.
Tokyo, Meteorological Society of Japan.
Tokyo, Physico-Mathematical Society o Japan.
Toronto, Meteorological Office.
Toronto, Observatory.
Tortosa, Observatorio del Ebro.
Trieste, R. Instituto Geofisico.

Tsingtau, Meteorological Observatory.
Turin, Società Meteorologica Italiana.

Upsala, Abisko Naturvetenskagliga Station.
Upsala, Observatoire Météorologique de l'Université.
Utrecht, K. Nederlandsch Meteorologisch Instituut.

Vienna, Akademie der Wissenschaft.
Vienna, Zentralanstalt für Meteorologie und Geodynamic.

Washington, Carnegie Institution.
Washington, Hydrographic Office.
Washington, National Academy of Sciences.
Washington, Office of the Panama Canal.
Washington, Smithsonian Institution.
Washington, U.S. Coast and Geodetic Survey.
Washington, U.S. Department of Agriculture.
Washington, Weather Bureau.
Wellington, N.Z., Government Statistician.
Wellington, N.Z., Meteorological Office.
Weymouth, Borough Medical Department.

Yorkshire Philosophical Society.

Zi-Ka-Wei, Observatoire Magnétique Météorologique et Sismologique.
Zomba, Meteorological Department.
Zürich, Schweizerische Meteorologische Zentral-Anstalt.

2. INDIVIDUALS.

A. A. Barnes.
D. C. Bates.
J. Baxendell.
F. Campbell Bayard.
Sir William Beveridge.
F. H. Bigelow.
G. Bigourdan.
G. E. Body.
C. E. Britton.
Dr. Ford A. Carpenter.
C. F. Casella & Co.
A. Challamel.
Dr. C. Chree.
V. Conrad.
Messrs. Constable & Co.
Librairie G. Doin.
J. Dover.
J. H. Elgie.
Prof. F. Eredia.
E. Fontseré.
W. L. Fox.
Messrs. Gauthier-Villars et Cie.
C. R. Harler.
N. Holden.
Henry Hubert.
W. J. Humphreys.
J. Hunter.
E. Huntington.
E. W. Jenks.
W. G. Kendrew.
K. Knoch.
E. Lamb.
G. Lawson,
A. F. Lebedeff.
J. Letzmann.
M. Manson.
Miss C. Marshall.
H. Mellish.
A. Merz.
T. Midgley.
F. Morey.
R C. Mossman.
E. W. M. Murphy.
Dr. J. S. Owens.
W. H. Pickering.
A. W. Preston.
E. J. Quayle.
J. R. F. Readman.
J. W. Redway.
L. F. Richardson.
P. Rintoul.
Rev. A. B. Rosenstein.
Jules Rouch.
Sir Wm. Schlich.
Dr. A. Schmauss.
E. Sifontes.
L. G. Tippenhauer.
Prof. R. De C. Ward.
F. J. W. Whipple.
I. R. Williams.
A. J. Wilmshurst.
R. P. Zealley.

The Editors of—

Ciel et Terre.
Geographical Teacher.
Nation and Athenæum.
Nature.
Observatory.
Revue du Ciel.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

January 17, 1923.

At the *Ordinary Meeting* the following candidates were balloted for, and elected Fellows of the Society:—

HARRY BEESTON, Sunnymead, South Street, Havant, Hants;
ROBERT JAMES CRAIG, Clonoran, Aughafatten, Co. Antrim;
JOSEPH GLAISYER, Barrow House, Keswick, Cumberland;
MARGARET S. HALL, The Gables, Weobly, Herefordshire;
JOSEPH MINTERN, Kilmurry, Passage West, Co. Cork;
WILLIAM HARCOURT PIPER, 67 Woodstock Road, Oxford; and
Capt. H. A. STAPLES, M.C., 19 Birchwood Road, Tooting Common, S.W.17.

January 17, 1923.

Annual General Meeting.

Dr. C. CHREE, F.R.S., President, in the Chair.

Mr. S. C. RUSSELL and Mr. M. A. GIBLETT were appointed Scrutineers of the Ballot for the Council.

The Report of the Council, which had been circulated to the Fellows present, was taken as read. The President, in moving the adoption of the Report, drew attention to the most important features and invited remarks from Fellows. Mr. L. F. RICHARDSON, Secretary, supported the motion.

It was then resolved "That the Report of the Council be received and adopted, and that it be printed in the *Quarterly Journal*" (p. 119).

It was proposed by Mr. R. INWARDS, seconded by Mr. H. E. CARTER, and resolved "That the thanks of the Society be given to the Council for their services during the past year." The President, in accepting the vote on behalf of the Council, expressed gratification at the way in which their services had been commended.

The President then delivered an Address on "Aurora and Allied Phenomena" (p. 67).

It was proposed by Mr. H. MELLISH, seconded by Dr. G. C. SIMPSON, and resolved "That the thanks of the Society be given to Dr. Chree for his services as President during the past year and for his Address, and that he be asked that the Address might be printed in the *Quarterly Journal*."

The President, in acknowledging the vote of thanks which had been passed, referred to Dr. SIMPSON's enthusiasm in observing aurora.

The SCRUTINEERS then declared the following to be the Council for the ensuing year:—

PRESIDENT.

CHARLES CHREE, Sc.D., LL.D., F.R.S.

VICE-PRESIDENTS.

REGINALD HAWTHORN HOOKER, M.A., F.S.S.
A. CRICHTON MITCHELL, D.Sc., F.R.S.E.
GEORGE CLARKE SIMPSON, C.B.E., D.Sc., F.R.S.
GILBERT THOMAS WALKER, C.S.I., Sc.D., F.R.S.

TREASURER.

WILLIAM VAUX GRAHAM, M.Inst.C.E.

SECRETARIES.

JOHN SOMERS DINES, M.A.
LEWIS FRY RICHARDSON, B.A., F.Inst.P.
GILBERT THOMSON, M.A., M.Inst.C.E., F.R.S.E.

FOREIGN SECRETARY.

RUDOLF GUSTAV KARL LEMPFERT, C.B.E., M.A.

COUNCILLORS.

CHARLES ERNEST PELHAM BROOKS, M.Sc., F.R.A.I.
JOHN BROWNLEE, M.D., D.Sc.
DAVID BRUNT, M.A., B.Sc., F.R.A.S.
WALTER WILLIAM BRYANT, B.A., F.R.A.S.
CHARLES JOHN PHILIP CAVE, M.A., J.P.
JAMES EDMUND CLARK, B.A., B.Sc.
RICHARD CORLESS, O.B.E., M.A.
FRANCIS DRUCE, M.A., F.L.S., F.R.G.S.
Colonel HENRY GEORGE LYONS, D.Sc., F.R.S.
HENRY MELLISH, C.B., D.L., J.P., F.R.G.S.
Sir NAPIER SHAW, D.Sc., LL.D., F.R.S.
FRANCIS JOHN WELSH WHIPPLE, M.A., F.Inst.P.

February 21, 1923.

At the *Ordinary Meeting* the following candidates were balloted for, and elected Fellows of the Society :—

Capt. ARCHIBALD HARRY BATHURST, c/o Messrs. Butterfield and Swire, Hong-Kong ;
GILES OWEN, 54 Townfield Lane, Barnton, Northwich, Cheshire ; and
GEORGE STEWART, Rotorua, New Zealand.

CORRESPONDENCE AND NOTES.

Royal Observatory, Greenwich. Report to the Council of the Royal Meteorological Society for the year 1922. (Communicated by the Astronomer Royal.)

Meteorological observations have been continued as last year. The temperature of the air varied between 90°·6 F. on May 24 and 24°·4 F. on the 3 days, January 24, October 26, and December 9. It reached 80° on 9 days, 6 of which were in May, and the remaining 3 in June. Air temperatures of 32° or less were recorded on 37 days, the largest monthly number being 11 in February.

The mean temperature for the year was 49°·0 F., being 0°·6 below the average. Of the separate months, April and July were below the average by about 4°, while May was 4°·5 above the average. The mean maximum temperature of 69°·9 for May was the highest since the corresponding month of 1893.

1478 hours of bright sunshine were registered, an amount slightly below the average for the last 25 years. May was the sunniest month, with 284 hours of sunshine, being 38 per cent above the normal. It was the sunniest May on record since 1909. Sunshine for February was 50 per cent above the normal, whilst November was correspondingly below the average, and also the most sunless November on record during the last 25 years. There were 72 sunless days, including 18 in November, 16 in December, and 12 in January. Nine days had at least 90 per cent of possible sunshine, the sunniest being August 26, with 94 per cent.

The highest reading of the solar radiation thermometer with black bulb *in vacuo* was 155°·0 F. on July 10, and the lowest reading on the grass 14°·5 on April 2. The difference between the highest and lowest radiation readings exceeded 100° on 38 days, the greatest difference being 118°·4 on June 22.

The total rainfall was 23·19 ins., or 1·14 below the 80 years' average, 1841–1920. The months of April and December were in excess of the normal by just over 1 in., contrasting with October with 1·7 ins. less than the average. There was one absolute drought of 18 days, from May 26 to June 12. On 5 days (January 19, April 4, June 15, August 6, and December 31) the rainfall exceeded half an inch, the greatest fall being 0·75 in. on January 19. The day is the civil day, reckoned from mdt. to mdt. Heavy rain also fell between 12 h. on July 5 and 3 h. on July 6, amounting to 0·83 in. There were 178 rain days in the year, 22 being in January and 21 in July. November, with only 8 such days, was a record in this respect since 1901.

The total movement of the air, recorded by Robinson's anemometer, was 106,486 miles. The greatest pressure recorded was 16·1 lbs. to the square foot on April 15. The greatest daily movement was 731 miles on April 15, and the greatest hourly velocity 43 miles for the hour ending 1 p.m. March 8. The least daily movement was 50 miles on November 21.

Meteorological Work at the Radcliffe Observatory, Oxford, 1922.

The following are the chief characteristics of the weather at Oxford during the year 1922 :—

The mean reading of the *Barometer* (reduced to 32° F.) was 29·704 ins., which is 0·023 in. lower than the mean for the preceding 67 years. The highest reading, 30·584 ins., occurred on November 16 ; the lowest, 28·391 ins., on December 30.

The mean *Temperature* of the air for the year was 48°·3 F., or 0°·7 below the mean for the preceding 94 years. The maximum temperature, 85°·6, was reached on May 23 ; and the minimum, 16°·2, on February 6. The lowest reading of the thermometer exposed on the grass was 11°·3 on February 6.

The differences of the mean monthly temperatures from the corresponding means for the preceding 94 years are :—

January	+1°·1	May	+4°·7	September	−1°·6
February	+0°·8	June	0°·0	October	−2°·6
March	−1°·3	July	−4°·1	November	−0°·9
April	−3°·9	August	−3°·6	December	+2°·9

The number of hours of *Bright Sunshine* for the year amounted to 1530, or 49 hours above the mean for the preceding 41 years.

The monthly differences from the mean are shown in the following table :—

	Hours.		Hours.		Hours.
January	+ 5	May	+75	September	−31
February	+24	June	+34	October	+39
March	0	July	−38	November	+ 2
April	− 3	August	−65	December	+ 7

Rainfall on the ground amounted to 26·426 ins. ; this total is 0·310 in. above the average for the preceding 107 years. The number of "rain-days" (0·005 in. or more) was 176.

The divergencies of the monthly amounts from the corresponding mean values for the previous 107 years were :—

	Ins.		Ins.		Ins.
January	+0·454	May	−0·640	September	−1·066
February	+0·649	June	−1·081	October	−2·357
March	+0·264	July	+1·009	November	−1·077
April	+1·039	August	+2·682	December	+0·434

Solar halos were observed on 147 days, parhelia being present on 25 days. The 46° halo was seen on September 25 (with zenithal halo) and October 29. On 3 days parhelia were observed with no halo. Contact arches were observed on 5 days. *Sun pillars* were seen on January 17, April 17, May 24, September 18, 27, and October 26.

Lunar halos were observed on 50 nights, on two occasions (May 6 and October 30) the 46° halo was also visible. Paraselenæ were seen on September 29 and October 3, and moon pillars on October 26, December 23 and 31.

The *Zodiacal light* was noted on 22 evenings between January 16 and April 24, and also on the evening of December 18, being accompanied on February 20 and 21 with the zodiacal band and counterglow, and on February 17 and 25 with the zodiacal band.

Additional features of the weather during 1922 are :—

The break-up of the great drought. This occurred in the first week of 1922, the drought having prevailed for more than eleven months.

During the night of April 1–2 the thermometer in the screen registered 8°·2 of frost, being the coldest April night for 30 years.

The rapid transition from cold conditions in April to fine sunny weather in May was very marked, the former month being the coldest April for 43 years and the latter the warmest May for 54 years. During the last eleven days of May some unusually high temperatures were recorded, the thermometer exceeding 80° on six occasions, the maximum reading, 85°·6, being the highest recorded for May. In no other May has the thermometer risen above 80° on more than two days. The sunshine for May, 269 hours, was very abundant, and with one exception (294 hours in 1909) is the highest recorded for this month.

The high temperature at the end of May continued during the first twelve days of June. The weather then became cold and unsettled, the maximum thermometer only exceeding 70° on seven days during the remainder of the year. The absolute maximum for July was 73°·3 on the 12th, in marked contrast to the temperature of July 1921, when the *mean* maximum was 78°·9. For August, also, the absolute maximum was exceptionally low, being 69°·7 on the 29th.

August was a very wet and sunless month, but was chiefly notable for the extraordinarily heavy fall of rain on the 6th, when between 5.20 p.m. and 11.40 p.m. the amount recorded was 2·2 ins., of which 0·75 in. fell in one hour (8.25–9.25 p.m.). The total amount measured at 9 a.m. on the 7th, 2·786 ins., is the heaviest fall in 24 hours since registration commenced in the year 1815. On only three other occasions during this period have two inches or more been measured in 24 hours, the greatest being 2·190 ins. at 8 a.m. on July 15, 1880. The total rainfall for the month of August, 5·132 ins., constituted a record, the previous largest amount for this month being 5·120 ins. in 1878.

The month of October, generally the wettest month of the year, was abnormally dry, with an unusual prevalence of keen Northerly to Easterly winds. The total rainfall, 0·500 in., is the smallest amount recorded for this month, the previous lowest total being 0·634 in. in 1842.

Arthur A. Rambaut,
Radcliffe Observer.

Radcliffe Observatory, Oxford,
February 21, 1923.

Reorganization of the Brazilian Meteorological Service.

A communication which has recently been received from Senhor Sampaio Ferraz, Director of the Brazilian Meteorological Service, shows the rapid progress which has been made in the advancement of official meteorology in Brazil since the reorganization of the service in June 1921. The service previous to that date had 97 second and third order stations with, in addition, 57 rainfall and co-operative stations. The numbers have now been increased to 152 and 237 respectively. The forecast service, which was almost non-existent prior to 1921, is now showing great activity. Daily charts are based on a network of 80 stations in Brazil, 18 in Argentina, and 6 in Uruguay. Forecasts for 24 hours in advance are issued not only by wireless telegraphy, line telegraph, and telephone, but even by radio telephony. In the large towns a system of flags for indicating anticipated weather changes has been adopted. Upper air work is carried out at 7 pilot balloon stations, while 2 kite stations are being constructed. The pilot balloon work is much hampered by the difficulty of transporting hydrogen from Rio de Janeiro to the aerological stations.

Another activity of the Meteorological Service consists in the issue of ten-day bulletins, giving the condition of the most important crops and showing how they have been affected by the weather. A flood-warning service has been inaugurated for the river Parahyba, and the same work will shortly be undertaken for the Amazon. European meteorologists will follow with interest the further development of this enterprising meteorological service in South America.

International Photographic Survey of the Sky.

It has been proposed by Colonel Delcambre, Director of the National Meteorological Office of France, also by Mr. J. Bjerknes of the Swiss Federal Meteorological Service at Zurich, that an endeavour should be made to obtain a synoptic survey of the skies of North-Western Europe by simultaneous photographs in all parts of the area.

The proposal is made to the International Commission for the study of Clouds. The seven days of the week beginning September 17, 1923, are indicated as days to be selected for a trial of the enterprise. At least three photographs are wanted for each day, as nearly as possible at the hours of the telegraphic observations, 7 h., 13 h., and 18 h. Mr. Bjerknes would like them to be repeated each hour.

A photographic camera is not included in the normal equipment of an official meteorological station, and to set up the equipment for this occasion is not practicable. It has been suggested that Fellows of the Society who are accustomed to use a camera might be willing to forward the plan by taking photographs of the sky on the days in question, and contributing the photographs to the Commission.

Any Fellow who is willing to join in this scheme should communicate in the first instance with Sir Napier Shaw, School of Meteorology, Meteorological Office, South Kensington, President of the Commission.

Meteorology at Harvard University.

Slow progress is made in the recognition of meteorology as a subject for study in British Universities, though the appointment of Sir Napier Shaw to a Professorship of Meteorology at the Imperial College of Science upon his retirement from the Meteorological Office two and a half years ago marked a welcome step forward. That at least one American University is ahead of this country in its recognition of the importance of meteorology is shown by the fact that at Harvard University it is now possible for an undergraduate to "concentrate" in Meteorology and Climatology. Concentration involves the taking, and passing, of six full courses, two of which courses must be in allied subjects, viz. Mathematics (one-half course) and Physics (one course). The courses in Meteorology and Climatology which an undergraduate must pass are the following: 1 (Elementary Meteorology); 2 (Climatology, General Course); 3 (Climatology of North America); 4 (Climatology of Latin America); 5 (Climatology of the Eastern Hemisphere); 6 (Selected Topics in Meteorology). These are all half-courses, with the exception of Meteorology 6, which is taken to count for one and one-half courses, and are all given by Professor R. DeC. Ward. Additional courses, provided primarily for graduate students, are a research course in Climatology, given by Professor Ward, and a research course in Aerography, given at Blue Hill Observatory by Professor Alexander McAdie.

It is interesting to remember that Harvard University is a daughter of Emmanuel College, Cambridge, Sir Napier Shaw's old college.

OBITUARY.

HENRY BRIDGER ADAMES.

For eight years Henry B. Adames took a leading share in preparing the annual Phenological Report, and had looked forward to continued service in this important section of our systematic work. He brought to it peculiarly valuable gifts of systematic neatness, initiative, an exceptional capacity and experience in dealing with figures, and a wide outlook.

Born at Chichester in 1882 and educated there, he passed direct to the Royal Observatory, Greenwich, becoming a member of the Royal Astronomical Society when 19. After six years with the Canadian Pacific Railway in Montreal (where he met again and married a life-long Chichester friend), he returned in 1909 to London and soon joined the Royal Meteorological and Geographical Societies. As he also kept up his astronomical work, especially on variable stars, his leisure time was most closely occupied. After a heavy strain at war work in a costings department he entered Doulton's in the same capacity. The post, though much to his taste, was most exacting, and there is no doubt that the combination proved beyond the powers of a constitution not over robust and undermined beyond what had been realized by an internal abscess. An operation last November was apparently successful. After nine days he was looking forward hopefully to renewed activities, when an entirely unexpected relapse proved fatal on December 9, 1922.

His was a strong, quiet, winning personality with a deeply spiritual nature, which endeared him irresistibly to all who came into touch with him, so that his colleagues on the Phenological Committee have been more keenly affected by their personal loss than by what to us as a Society is of greater importance, the removal of one so peculiarly fitted for the task he had undertaken.

On the fly-leaf of a favourite author was found inscribed this quotation:—"It would be well for my memory that others walking in the sunshine should be softened as they thought of me."

J. E. C.

WALTER WILLIAM BRYANT.

Walter William Bryant was born on December 9, 1865, at Forthampton, Gloucestershire, and his infancy was spent in that village, where his father was a schoolmaster. He received his earliest education at St. George's School, Brampton. Thence he obtained a scholarship to Pembroke College, Cambridge, and graduated 21st Wrangler in the Mathematical Tripos of June 1887.

In the following year he obtained a second class in Part I. of the Natural Science Tripos. After leaving the University he acted as private tutor and, later, as assistant master, firstly at Cowbridge and then at Dulwich College. For a short period following this latter appointment he was engaged on mathematical coaching, and in February 1892, after competitive Civil Service examination, was appointed an assistant at the Royal Observatory, Greenwich.

The meridian observations with the Transit Circle were his first charge—one of the greatest importance because they constitute the fundamental work of the Observatory. He entered into the work with enthusiasm, and quickly showed remarkable aptitude for it. His methods, energy, and zeal were, by force of example, extended to his fellow-observers, but it was mainly due to his own efforts that the annual output of his Department was nearly doubled. He proved a most expert observer, and although he worked always at a very great rate he never sacrificed accuracy for speed—his remarkable capabilities enabled him to combine the two.

From 1897 onwards he took regular observations with the 28-inch Equatorial, and here again, in the measurement of Double Stars, he exhibited observational skill of the highest order. This work demands patience and the utmost precision, and Bryant proved that he possessed a full share of these qualities. His measurements were extremely good, especially in the case of the most difficult close pairs.

On the retirement of Mr. W. C. Nash at the end of 1903, Bryant was given the Superintendence of the Magnetical and Meteorological Department. Keen and ardent astronomer as he was, the change of work was not at first congenial to him. His interest, however, gradually increased, and in a short time he had a thorough grasp of his new subject.

The work of this branch of the Observatory is, of necessity, largely of a routine character; nevertheless, Bryant found much to engage his attention. He became particularly interested in averages, and his wonderfully retentive memory enabled him, when questioned, to state off-hand any outstanding data in the long series of Greenwich Meteorological Records. His colleagues put this faculty to a severe test on occasions and received correct answers without fail. A little before his appointment a beginning was made of the transfer of the Magnetic and Meteorological Instruments to a better site in Greenwich Park. The complete transfer was in progress for a number of years, and to the installation and adjustment of the instruments he gave great care. The night-sky camera—a complementary record to the sunshine register—was introduced under his superintendence.

Bryant was elected a Fellow of the Royal Astronomical Society in 1892, and of the Royal Meteorological Society in 1906. In the latter Society he held in turn the Office of Secretary (1916–20), Vice-President (1920–21), and at the last annual meeting was elected an ordinary member of the Council. He was a most regular attendant at the meetings of these Societies, and was also an unfailing visitor at those of the British Astronomical Association, the Geophysical discussions of the Royal Astronomical Society, and the informal fortnightly discussions instituted by Sir Napier Shaw at the Meteorological Office.

He was always prepared to join in discussions on astronomical, physical, or meteorological matters, and contributed several papers to the *Quarterly Journal* of the Royal Meteorological Society. His writings included a *History of Astronomy*, published in 1907; biographical studies of Galileo and Kepler; many reviews in *Science Abstracts*; and contributions to the *Morning Post*, to which journal he was a regular correspondent.

Bryant's recreations were music, chess and hockey, and he excelled in all three pursuits. He sang in various church choirs from the age of six and made full use of a good bass voice as a member of the Handel Festival Choir for about 30 years. While at Cambridge he had the honour of representing his University as a chess player in the Inter-University Chess match. He was one of the founders of the Royal Observatory Hockey Club (1892) and continued an active member until well on into middle life, and long after some of his younger co-founders had given up the game for less strenuous forms of exercise.

On the 17th of January Bryant was engaged in field magnetic work and complained of illness. He was medically examined, but at first it was not thought that surgical attention was immediately necessary. His illness, however, developed rapidly, and an operation was performed which much weakened him. A second and much more severe one had a fatal termination on the 31st January.

Bryant leaves a widow and eight surviving children to mourn their loss. He was a kindly, conscientious, and Christian gentleman, and his untimely death is keenly felt by his colleagues at Greenwich, his large circle of friends, and the clergy and members of the Church which he attended. To all of these he rendered, in various ways, unsparing and unselfish service. D. E.

Dr. J. W. BALLANTYNE.

On the 23rd January, at a nursing home in Edinburgh, occurred the death of Dr. John William Ballantyne, following an illness from appendicitis.

Dr. Ballantyne was born at Eskbank, Dalkeith, in 1861, and graduated M.B. at Edinburgh University in 1883. He filled many important professional positions, and his published works giving the results of original research entitled him to rank high amongst modern medical and pathological writers.

He was elected a Member of the Scottish Meteorological Society in 1913.

Mr. H. D. GARDNER.

Mr. Henry Dent Gardner, whose death occurred at Fairmead, Eastbourne, on August 12, 1922, was a member of the firm of Messrs. E. Dent & Co., watch and chronometer makers. His business life led him into close touch with observatory requirements, and stimulated an interest in astronomy and meteorology which he had long possessed. Mr. Gardner kept a careful record of the weather at Eastbourne, and maintained there barograph and thermograph records for about ten years.

He was elected a Fellow of this Society in 1900.

Prof. J. RADCLIFFE.

The death of Prof. Joseph Radcliffe, head of the Sanitary Engineering Section of the Manchester College of Technology, occurred at his residence at Crumpsall on February 16, 1923, after a brief illness, at the age of sixty-six years.

Prof. Radcliffe was born at Rochdale, and began to earn his living at a very early age. He attended evening classes with such success that he was one of the first scholarship students sent by the Rochdale Pioneers' Co-operative Society to the then Owens College at Manchester. He subsequently became engineer at the Todmorden waterworks, and in 1891 commenced his career as professor in the Manchester College of Technology. The Victoria University conferred on him the degree of M.Sc. Tech. in 1906.

Prof. Radcliffe was elected a Fellow of this Society in 1889.

Mr. C. L. Wragge.

By the recent death at Auckland, New Zealand, of Mr. Clement L. Wragge, formerly head of the Weather Bureau at Brisbane, meteorology has lost an enthusiastic worker. Mr. Wragge was born at Stourbridge on September 18, 1852, and was educated at Uttoxeter Grammar School. After a short period of service in the Surveyor-General's department at Adelaide, he returned to England, where he founded several meteorological stations in North Staffordshire.

When the Scottish Meteorological Society wished to establish a meteorological observatory on Ben Nevis at 4400 feet above sea-level, they were fortunate in securing the services of Mr. Wragge, who, during the summers of 1881 and 1882, daily ascended the mountain and took regular observations. The Scottish Meteorological Society, in an appeal for public funds to found a permanent observatory on Ben Nevis, referred to "the observations made by Mr. Wragge with such skill, endurance, and enthusiasm during the last two summers on Ben Nevis." That very considerable endurance was required for the work was graphically shown in an article in the *Times* of September 1, 1881.

Returning to Australia, Mr. Wragge served as Government Meteorologist for Queensland from 1887 to 1902, and he established the Weather Bureau at Brisbane, as well as high-level meteorological stations on Mount Wellington and Mount Kosciusko (7336 feet).

Mr. Wragge was an enthusiastic devotee of map meteorology, and in tracing the movements of cyclones and anticyclones he was accustomed to give these systems Christian names in his official reports. His views and methods, especially in later years, were frequently unorthodox.—(Reprinted from *Nature*, **111**, 1923, pp. 23-24.)

Mr. Wragge, whose death occurred on December 10, 1922, was elected a Fellow of this Society on November 19, 1879. He was for several years an observer for the Society and an occasional contributor to the *Quarterly Journal.*

The following deaths are also recorded with regret:—

Mr. Henry James Bailey, D.L., J.P., of Rowden Abbey, Bromyard, elected 1907, died August 21, 1922.

Mr. P. A. Cobbold, M.A., J.P., F.C.S., elected 1908, died December 2, 1922. Mr. Cobbold's death was caused through forest fires in Ontario in the previous autumn.

Rev. G. S. Hitchcock, D.D., elected February 16, 1921, died July 10, 1922.

Mr. Henry Foulkes Kingdon, elected 1907, died August 1922.

Mrs. Wilson Pease, elected 1917, died October 25, 1922.

Mr. Fielden Ramsbotham, elected 1879, died May 29, 1922.

Mr. J. R. Tustin, F.C.S., elected 1900, died December 24, 1922.

Mr. Samuel Walker, elected 1888, died December 10, 1922.

REVIEWS.

Life Cycle of Cyclones and the Polar Front Theory of Atmospheric Circulation. By J. Bjerknes and H. Solberg. *Kristiania, Geophysiske Publikationer,* 3, 1922, No 1. Pp. 18. 4°. Price 2 kr.

In an early paper on the polar front published in *Nature* some years ago Prof. V. Bjerknes showed the line of separation of polar from equatorial air as extending from east to west around the globe with a chain of cyclones spaced along its length. In the practical development of the subject since that time attention has chiefly been directed to the characteristics of individual cyclones as units and not to the chain of disturbances as related members of a common system. The present paper shows an advance in the direction indicated by Prof. Bjerknes, in that cyclones are no longer regarded as individual units but are grouped into "families," all the members of one family being intimately related to one another. The family of cyclones has for its parents the warm and cold currents which flow in contrary directions on the two sides of the polar front, the warm equatorial current flowing north-eastward on the one side, the cold polar current south-westward on the other. A change of view has taken place since the time when the polar front was regarded as a continuous line round the globe; it is now represented as a series of separate sections, each of which runs in a general S.W. to N.E. direction from the tropics to polar regions. Each section is the home of a family of cyclones. A complete family consists of four or more individual cyclones, each of which follows, in its eastward movement, a more southerly track than its immediate predecessor. The life-history of these cyclones from birth to death is traced, the death of a cyclone occurring when it becomes completely surrounded by cold polar air. The last member of a family passes so far south that the polar air in its rear breaks through to join the Trades, after which an extensive high-pressure area moves eastwards before the arrival of the first cyclone of the new family. These families are given consecutive numbers by the Norwegian meteorologists, the numeration recommencing with each new year.

A study of the paper provokes the question, Under what conditions does a new family spring to life or does the existing series of families for ever march round the globe revisiting Europe in constant sequence? The authors seem to incline to the latter view as representing the underlying principle, for they say, "if we disregard the obstacles formed by the large continents, the cyclone families and intermediate moving anticyclones may be imagined to travel continually round the pole." One begins to speculate whether one family might not have characteristics differentiating it from the others so that it could be recognised on successive visits; but such speculations are premature. The theory of families is yet young and not fully developed.

The paper is clearly expressed and full of interest to all engaged in the study of daily weather maps, and while parts of it may not be entirely convincing, all at least provoke much thought. J. S. Dines.

Meteorologische Optik. By J. M. Pernter und F. M. Exner. Zweite Auflage. Wein und Leipzig (Wilhelm Braumüller), 1922. 8°. Pp. xvi + 907. 15s.

The well-known work on Meteorological Optics which was commenced by J. M. Pernter and completed by F. M. Exner, his successor as Director of the Austrian Meteorological Service, is a storehouse of information on the various aspects, observational and theoretical, of the subject. Its influence on the growth of knowledge has been great. In the circumstances the call for a second edition could not be met by a mere reprint. Exner, who tells us that he undertook the revision as a pious task in memory of his friend, has carried it out in a very human way. The judgments that are set before us are Exner's, but we are continually reminded that Pernter, in the first edition of this work, stated so and so.

The ideal book on Meteorological Optics would abound in coloured illustrations. It is pleasing to find a modest beginning here, a coloured plate showing curious forms assumed by the rising sun. The picture suggests some mirage effect, but one is not prepared for the lesson which is brought home by the account of A. Wegener's work on this subject. Every one has had the experience of watching the sun setting in a clear sky and seeing it crossed by a black bar, apparently a thick cloud, when no cloud or smoke was to be expected. Wegener tells us that it is no cloud but a reflection of the earth; there is a temperature inversion such as produces the "superior" mirage, and the little light that reaches the eye from the part of the inversion layer represented by the bar has not come from the sun, but from the earth.

The possibility of the occasional existence of a vertical boundary between hot and cold air and the production of images by reflection at such a boundary has recently been put forward[1] in explanation of a remarkable mirage reported from Cape Wrath. It is therefore of interest to notice that there is only one explicit instance of such a reflection in the *Meteorologische Optik*. This instance dates back to 1818: a sailing-boat was seen on Lake Geneva through a telescope, and presently what looked like another boat parted from it, the two making for opposite shores. It may seem frivolous to suggest that there were actually two boats on the lake, but no other explanation seems to meet the case; certainly the suggestion (due to Biot and quoted with approval by Pernter) that a sharp difference of temperature would persist over the lake at the edge of the shadow of a mountain range is not plausible, especially when it is remembered that there was sufficient breeze for sailing. Reflection at vertical surfaces is also invoked to explain some of the complicated phenomena classed under the heading Fata Morgana. Many of these phenomena could have been discussed with advantage on the lines of a paper by Nölke (*Phys. Zs.* Bd. 18, 1917, S. 124), which provides Exner with some useful paragraphs. Many years ago Tait discussed the rays reaching the eye from various directions, pointing out that if the atmosphere were stratified horizontally with the warmer, lighter air above, then each of the rays which curved sufficiently would have a horizontal tangent at its highest point. With certain assumptions as to the distribution of temperature, Tait was able to plot a curve on which would lie the highest points of all the rays reaching the eye in a certain azimuthal plane. Nölke draws such a locus and, at the same time, the locus of the highest points of the rays proceeding from a specified point of the object under observation. The number of common points of the two loci is evidently the number of images which are to be seen. It is an obvious corollary that if the two loci touch one another there will be a drawn-out image of this point of the object, and great distortion of the object as a whole.

On the question which classes of crystals are responsible for various phenomena of the halo complex, Exner follows Hastings and Besson. Pernter had accepted the assumption that a long thin crystal would gradually subside through the air with its axis vertical, and that a flat crystal would sink edgewise. The fact is that the long crystal, if symmetrical, will generally float horizontally, and the flat crystal will remain horizontal or spin or flutter downwards. It is not yet certain how the high proportion of hexagonal prisms with vertical axes required for the formation of mock suns and of the circumzenithal arc is maintained; the suggestion of Pinkhof (*Met. Zs.* 48, 1920, p. 63) that the presence of a strong electric field is the cause seems plausible, but it requires support from arithmetic and experiment.

As to the vexed question whether the appropriate name for the brilliant arc seen about 46° from the sun and convex to it is "upper tangent arc of the halo of 46°" or "circumzenithal arc," Exner admits that the arc is frequently separated from the halo; and, moreover, he shows that the theory of Bravais, which is consistent with the true circumzenithal arc, is on a sounder basis than that of Galle, which favours the tangent arc. He is convinced, however, by a recently published observation of Pinkhof's, in which the distance between the moon and the middle of the arc was established with the help of the star Capella. Calculation gave 45° 40′, just the distance for Galle's arc. For the actual altitude of the moon, 29°, the arc of Bravais would have been 48° 24′ from the moon. Personally, I suspect a flaw in this observation, and in the absence of further evidence I shall count all such phenomena as circumzenithal arcs.

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[1] *Nature*, **111**, 1923, p. 222. D. Brunt, "A double-vertical reflection mirage at Cape Wrath."

Exner shows great reluctance to accept Dr. Simpson's theory that iridescent clouds and other diffraction phenomena are to be explained by the presence of minute water drops at temperatures far below the freezing point. In consequence of his conviction that bows of about 33° radius centred about the point opposite to the sun in very cold weather could not be formed by reflection from water drops, Pernter named such bows "Bouguer Halos," and this in spite of the facts:—

(1) that experienced observers were using the terms rainbows or mistbows;
(2) that his own work had established the explanation of mistbows by an application of Airy's rainbow theory;
(3) that the bows appeared at times when no other halo phenomena were present;
(4) that no tenable explanation of a halo of appropriate size was to be found.

Exner does not seem to have considered the case critically; at any rate, he has not seen how desirable it would be to "scrap" the Bouguer halo. He admits, however, that some of the observations of mistbows below the freezing point must stand. We can agree with him that further study of the undercooling of raindrops is much to be desired.

As to the last section of the book, which deals with such important subjects as the absorption of light by the atmosphere, the most fundamental change is one mentioned by Exner in his introduction. In Pernter's scheme the last section was allotted to phenomena due to disturbing particles (trübenden Körperchen). We are now aware that the molecules of the air are responsible for many of these phenomena formerly attributed to grosser matter (notably for the blue of the sky), and Exner's name for the section in question is The Atmosphere as a Turbid Medium.

It would be a boon to English students of meteorological optics if a treatise as thorough as Pernter and Exner's great work (but less diffuse) were available in their own language. F. J. W. WHIPPLE.

Climatic Changes, Their Nature and Causes. By ELLSWORTH HUNTINGTON and STEPHEN SARGENT VISHER. New Haven (Yale University Press); London (Humphrey Milford: Oxford University Press), 1922. 8°. Pp. xviii + 329. 17s. 6d. net.

There is a well-known meteorological paradox in which, as the sun emits more heat, the earth becomes colder. Hitherto this has been accepted, if at all, only for small fluctuations such as those of the eleven-year sunspot period, but in "Climatic Changes" it is applied to explain most of the great climatic vicissitudes of geological time, including Ice Ages and long periods of genial climate. The theory is termed the "Cyclonic-Solar" and is followed into all its ramifications with great ingenuity.

Since the earliest known geological times the earth's climate has kept to the bounds within which life is possible, but with a gradually increasing complexity as the earth grew older. This essential uniformity has been traversed by long slow waves, lasting millions of years, termed "geological oscillations," due mainly to such purely terrestrial factors as the condition of the earth's interior, the salinity and movements of the oceans, and the amount and composition of the atmosphere. Superposed on these long slow changes are an infinite series of shorter fluctuations of all lengths from that of an Ice Age to variations lasting only a day, and the great majority of these are considered as due to solar variability, especially through its effect on storminess and the positions of the storm tracks.

When sunspots reach a maximum storms are most numerous and follow northerly tracks, while at spot minimum the reverse is the case. Now imagine a sunspot maximum increased tenfold. The earth is receiving an abnormally large quantity of heat, but evaporation is great, storms are very numerous, and much heat is carried to the upper regions of the atmosphere, where it is easily radiated to space and lost. Hence the whole earth grows cool and rainy, and if the sun becomes hot enough, the result is a glacial period. On the other hand, if the sun is quiet and radiates little heat, storms are few or absent, and we have a long period of mild uniform climate. But even this is hardly enough to account for some of the rich sub-polar floras and another process is tentatively brought into play, namely, the reversal of the oceanic circulation. Under intense evaporation in the tropics the surface water becomes saline and dense, and sinks to the sea-bottom, to travel poleward there and rise to the surface in sub-polar latitudes where it causes a highly favourable climate. The surface currents are all from the poles to the equator, but since there is no ice, they are nowhere cold.

The record of the rocks shows, however, that periods of low temperature have commonly been associated with periods of high and extensive lands, while mild climates have accompanied extensions of the oceans. High and extensive land areas are admitted to be a favourable condition for the action of the "Solar-Cyclonic" agency to produce glacial periods, but arguments are brought forward to show that earth changes cannot be the chief cause of climatic changes. In fact, it is suggested that the position is reversed, and climatic changes cause the earth-movements! For when the earth is in a state of strain, and increasing sunspots cause growing storminess, the rapid barometric changes involved act as the blows of a hammer and cause readjustments, resulting in earth-movements. The present-day occurrences of earthquakes are shown to support this hypothesis.

The Permian Ice Age is usually a great stumbling-block for glacial theorists, since in this case the centres of ice accumulation were near the equator, and the cold temperate regions were relatively ice-free. Here the Permian is considered to be an extreme case in which the storm tracks and consequent snowfall on the high-lands were displaced into very low latitudes indeed, while on the poleward side of the tracks there were, except in isolated maritime localities, dry air and desert formations.

The solar variations are supposedly due to the "electro-magnetic" effects of other bodies on the sun. The eleven-year period is due in this way to the action of the planets and especially Jupiter—an unsatisfactory position, the reasons for which are to be given in a companion volume not yet published, entitled "Earth and Sun." Now if Jupiter has such a marked effect, a very much larger "star" which approaches our sun at any time must cause a very much greater disturbance. A census of the chief stars whose distance and relative direction of motion are known gives an idea of the disturbing effect of the nearest of such stars on the sun. It appears that the most disturbing star is Alpha Centauri; this is double, its two components rotating on elliptical orbits in eighty-one years, and an eighty-one year period is considered to be important in the weather. The total disturbance of all the stars considered reached its last maximum about 30,000 years ago, during the crest of the Wurm Glacial Period.

That is a brief outline of the most stimulating contribution to the problem of climatic changes which has appeared for many years. Few meteorologists will find themselves in entire agreement with the authors, and many will even doubt the validity of the basic assumption. In the eleven-year sunspot period we have certain very small changes—with the sun at its hottest the earth as a whole is about 0·5° C. colder than with the sun at its coldest. Can we extrapolate, and say that an amplification of the solar cycle, both in length and intensity, would give us at the sun's hottest an Ice Age on the one side and at its coldest, palms and cycads within the Arctic Circle on the other side? It seems an extravagant proposition, and yet all the facts slide so neatly into place, and all objections are met so skilfully, that at the end one is almost convinced.

C. E. P. B.

La Prévision scientifique du temps. Traité pratique. By GABRIEL GUILBERT. Paris (Augustin Challamel), 1922. 8°. Pp. ix + 439, pls. 6. 22 frs.

M. Guilbert, in an introductory note, explains that he became a meteorologist by a long first-hand study of the weather without the aid of books and teachers. By the year 1886 he had devised a system of forecasting by observation of cloud only. Later he devised a system based on the study of isobaric charts, which was published in 1891. Since then he has employed a combination of the two systems, and his forecasts have been published daily for some time past in *Le Matin*. M. Guilbert has his own system of classification of clouds; he regards the cumulo-nimbus cloud of the International Classification as a development from cirrus and gives it the name of cirro-nimbus. The words stratus and nimbus are used only in a subsidiary descriptive manner, the three primary types being the cirrus (ice particles), the transitional (snow turning to water droplets, under conditions of super-saturation), and the cumulus (entirely aqueous).

In his system of forecasting with synoptic charts, the control of surface pressure by surface winds is postulated. The prediction of the distribution of surface pressure, by the application to existing surface winds of certain empirical rules, is made the basis of all his predictions of the weather. In these rules, which number twenty-five, the departures of surface winds from the "normal" wind for the existing pressure gradient ("normal" being taken as 46 per cent of the geostrophic wind) play the most important part. Since emphasis is laid upon the importance of even an isolated "abnormal" wind in forecasting, it is surprising to find that no allowance is found necessary for differences of exposure at different stations. The rules are stated in full on pages 120-124. The main ideas underlying them appear to be that winds above "normal" strength result in a rise of pressure during the next 24 hours and conversely; also that depressions tend to move towards regions where winds are either below "normal" or else "normal" (or above "normal") and divergent; and that barometric changes that are taking place to the right of an observer standing with his back to the wind tend to pass across to the regions on his left. M. Guilbert attempts to explain, in the earlier part of his work, how to apply his rules in practice, and how to harmonize the often contradictory conclusions that would be reached by their strict application, but does not succeed in making matters very clear. In one of the examples given of what is claimed to be a successful application of his system, the winds in a depression centred over Holland on September 30, 1918, were such as to lead him to expect, with absolute certainty, that the system would completely fill up without movement in 24 hours. Charts are reproduced in order to show that this actually happened. Charts made at the Meteorological Office for shorter intervals of time and a wider area show, however, that this depression did not, as a matter of fact, fill up without movement. The storm had arrived over Holland after traversing the English Channel on the previous day and was clearly shown over the Baltic on the morning of October 1, by which time it should, according to calculation, have quite dispersed. A wind of storm force at Hammeren and a well-defined cyclonic circulation showed that the system still possessed considerable energy.

Following an exposition of the twenty-five rules is a series of chapters dealing in turn with the forecasting of wind, rain, fog, etc. The author then turns his attention to the theoretical aspects of cloud and rain. He rejects the generally accepted theories which attribute the greater part of rain to condensation brought about by reduction of atmospheric pressure. To him all rain is melted snow, this snow originating in the highest forms of cirrus and growing in quantity by condensation while descending nearer to the ground, the details of the process being impossible to comprehend at present. The close connection between the annual rainfall of a place and its altitude above sea-level he explains by supposing that the melted snow begins to evaporate as it descends, and this process is necessarily more effective for stations near sea-level than for those high up. In attempting to explain, however, the greater rainfall on the windward than on the leeward slope of a hill as being due to the smaller loss by evaporation of rain falling through moist ascending than through dry descending air, he loses sight of the fact that for equal altitudes there would be no such difference in humidity, unless moisture had been removed in precisely the way which he regards as impossible, namely, by dynamical precipitation. Although most, if not all, of M. Guilbert's theories about the physical processes of weather will prove unacceptable to the majority of meteorologists, the work bears evidence of a very close and long-continued study of the weather.

E. V. N.

A Dictionary of Applied Physics. Vol. III., Meteorology, Metrology and Measuring Apparatus. Edited by Sir Richard Glazebrook, F.R.S. In five volumes. London (Macmillan and Co.), 1923. 8°. Pp. vii + 839. 63s. net.

Attention is drawn to the publication of the third volume of the above dictionary of applied physics in which the following articles on meteorological subjects appear :—Physics of the atmosphere, by D. Brunt, M.A. Measurement of solar radiation, by Wm. W. Coblentz, Ph.D. Meteorological instruments, by Richard Corless, M.A. Investigation of the upper air, by W. H. Dines, F.R.S. Radiation, by W. H. Dines, F.R.S. Thermodynamics of the atmosphere, by Sir Napier Shaw, F.R.S. Humidity, by Sidney Skinner, M.A. Meteorological optics, by F. J. W. Whipple, M.A. Atmospheric electricity, by C. T. R. Wilson, F.R.S.

QUARTERLY JOURNAL

OF THE

ROYAL METEOROLOGICAL SOCIETY

VOL. XLIX.] JULY 1923 [No. 207

REFORM OF THE CALENDAR.

A Discussion opened by
COLONEL E. GOLD, D.S.O., F.R.S.,
Assistant Director of the Meteorological Office,
At a Meeting of the Society on 21st February 1923.

COLONEL E. GOLD:—The only way of making a really satisfactory reform of the calendar, and one to which I think indeed many people have aspired in the past without much success, is to accelerate the sun and retard the moon. If one could only make the year 360 days and the lunar month 30 days, the consideration of an ideal calendar would be a very simple proceeding. The question of the calendar might be regarded as primarily an astronomical one or an ecclesiastical one, but nobody who has had to do with meteorological statistics can be indifferent to any prospect of an improvement which would remove the difficulties which are due to the incongruity between the week, the month, and the year:—February with its 28 days—a week in one place in one year and in another place in another year—all make the compilation of statistics very difficult. In the *Weekly Weather Report* of the Meteorological Office in its old form there is a table giving summaries for periods of four weeks. These summaries are not comparable with the monthly summaries and involve separate compilations.

What conditions must the calendar satisfy if it is to be as far as possible ideal from the meteorological point of view? First, we must be able to have a period shorter than the month. We must have something of the nature of a weekly period. It is very desirable that this short period should come in the same position in the course of the year from year to year and not change about, and in the same position each month, so that monthly values can be directly computed from weekly values. It may sound difficult to achieve if you think of the year as it is, but it would be desirable from the point of view of meteorology and would simplify all computations. On this criterion the existing week stands condemned. It is, in fact, a statistical tragedy to continue it in the Meteorological Office publications and in the returns of the Registrar-General. It is also desirable that the week should preserve the same length throughout the year, but this is not absolutely essential. Naturally also it is desirable to have the months as nearly as possible equal. The present system of months cannot be considered on the whole a bad one if February received back the day that Augustus stole from it to make his month as long as the month of Julius Cæsar, and the advantage of having twelve months in the year is one that is not to be lightly set aside. The number twelve enables one to get a quarter, a half, and a third without difficulty.

Dr. Marvin has been moved to issue a short circular indicating what he thinks ought to be done by meteorologists to get a calendar to suit their purpose. His proposal is briefly that we should make all the months, months of four weeks; weeks of seven days. That satisfies one of the criteria for an ideal system. It makes the monthly statistics easy to derive from the weekly statistics. He achieves this by having thirteen months in the year, and one day which can be placed, as he suggests, at the end of the year, or, if we preferred it, in any other place; one day out of the ordinary reckoning, in leap year two days. Each 14th day of the month in his scheme would always be a Saturday. That naturally is a very great advantage. Dr. Marvin says: "A new calendar of this character can be introduced without the slightest appreciable break in the present chronology at a time when the first day of the year falls on Sunday." He suggests that his new calendar should be introduced in 1928, because 1st January 1928 is a Sunday, and the first day of the month in Dr. Marvin's system is a Sunday. One of the greatest disadvantages of this system is the thirteen months. The months do not fall into quarters, and thirteen is an extraordinarily inconvenient number. You could almost carry in your head the necessary sines and cosines for the twelve months or the twenty-four hours, but to carry in your head sines and cosines for harmonic analysis with thirteen months would tax most of us. Dr. Marvin says: "The quarters by the new calendar would contain exactly 13 weeks, that is, one week more than just three months. However, each such quarter would embrace exactly 78 working days, and present other advantages in business and financial affairs which quite offset the seeming inconvenience of the fractional months." No doubt we could get over the difficulty, but it seems to be almost a fatal objection to Dr. Marvin's proposal that his months do not fall into quarters. The French Revolutionary calendar was drawn up by Monge and Lagrange; it lasted for 12 years and then had to be given up. This indicates the difficulty of reforming the calendar except by international agreement.

All schemes put forward hitherto go on the hypothesis that you must have a seven-day week. There is another possible length of the week, and that is six days. If you have a six-day week, Sunday to Friday, and a five-week month, you still retain twelve months in the year. Weekly statistics would go into monthly statistics quite simply. You have five days to dispose of; a possible way of allocating these would be to have a Saturday every quarter, and two Saturdays in the last quarter. This will not introduce any great variations into the weekly statistics, and it leaves the monthly statistics directly computable from the five sets of weekly statistics. I commend this as a thoroughgoing reform which would make all computations much simpler and give the other advantages claimed for the reform put forward by Dr. Marvin without any of its disadvantages.

The following extracts from a letter by Mr. W. D. Laing, of Nairn, N.B., were read by the Secretary:

Granted that the division of the year into twelve months of as nearly as possible equal length is the most suitable arrangement for the meteorologist that can be devised, it remains to put this arrangement on a scientific basis, and it appears to the writer that this can only be done by putting the months in a definite relation with the seasons as determined by the solstices and equinoxes. The dates on which these events occur in a clear majority of years are, beginning with the vernal equinox, 21st March, 22nd June, 23rd September, and 22nd December. Let us start the first month of the year with the winter solstice, as being analogous, for observers in the northern hemisphere at least, to the commencement of the day at midnight, and also as involving the least possible disturbance of the existing calendar. Now, owing to the eccentricity of the earth's orbit, the interval from the autumnal to the vernal equinox is shorter by 7 days than the complementary interval from the vernal to the autumnal equinox, the exact number of days in these periods in an ordinary year being 179 and 186 respectively. We find, therefore, that by arranging the year in two portions, the first consisting of seven consecutive months of 30 days each, and the second of five consecutive months of 31 days each, only one of the dates mentioned (*i.e.* of the solstices and equinoxes) will be displaced from its position as the starting-point of a month, and that by a single day. In leap years there will be no such displacement. Our calendar, then, will be complete as follows:

No. of Month.	Month.	No. of Days.	
1	*December* 22–January 20	30	
2	January 21–February 19	30	
3	February 20–*March* $\left.{20 \atop 21}\right\}$	30	
4	*March* $\left.{21 \atop 22}\right\}$–April 20	30	(31)
5	April 21–May 21	31	
6	May 22–June 21	31	
7	*June* 22–July 22	31	
8	July 23–August 22	31	
9	August 23–September 22	31	
10	*September* 23–October 22	30	
11	October 23–November 21	30	
12	November 22–December 21	30	
	Total . .	365	(366)

N.B.—In the above table I have inserted the necessary corrections for leap years, and the dates of the solstices and equinoxes are printed in italics.

This calendar, it will be seen, bears a striking resemblance to the French Republican calendar. In conclusion, I would mention that the calendar I have briefly described has been used by me for over six years with what I consider satisfactory results, and that the experience of these years has suggested to me no improvement which I could make upon it.

Mr. P. M. Macintyre of Callander forwarded a proposal by Mr. Alex. Philip, F.R.S.E., the chief first recommendation of which involves the transference of a day from August to February to equalise the lengths of the months. A further suggestion is that the day added to February in leap years, February 30th, should be called a "leap day" and be regarded as a *dies non.* By considering May 31st (which would be called Whitsun day) as another *dies non* in each year, and following it by a Sunday, each quarter would consist of 91 days, that is exactly 13 weeks, and would start on a Sunday.

The Rev. D. HOLLAND STUBBS, of Fareham, who was unavoidably prevented from attending, forwarded a proposal which closely resembled that of Dr. Marvin. Mr. Holland Stubbs divides the year into thirteen equal months of 28 days each. To complete the year he has an undated intercalary day, which he suggests should be a world's holiday and be called "Peace." In leap years a second intercalary day is suggested, which should also be a world's holiday and be called "Happiness." In this proposed reformed calendar Mr. Holland Stubbs has set out the Church's festivals and Saints' days and other recurring dates. Under his scheme the reform of a "fixed Easter" is introduced, as he arranges Easter Day on the eighth day of the fourth month. This date corresponds to April 2nd in the present calendar in a non-leap year.

DISCUSSION.

Mr. L. C. W. BONACINA said that after 2000 years the calendar months have become enshrined in literature. They have come to mark steps in the seasonal phenomena of nature and it would be vandalism to overthrow them. The rectification by Gregory XIII. did not destroy the natural landmarks of the calendar, viz. the solstices and equinoxes—the changes of ten days not being of much climatic significance. It would entail hopeless confusion to retain the same names of months with different seasonal significations; we should always be having to think and specify whether we were talking of the old or new months. In Dr. Marvin's scheme there is also the awkward question that the solstices and equinoxes would be 6½ months apart, and no month would be exactly opposite another along the earth's orbit, as is the case with the present calendar. But, apart from these specific objections, would it be worth while from the climatological point of view to have to translate all the records from one calendar into the other? The proposal by Mr. Philip is more manageable, as it introduces only slight changes.

Sir NAPIER SHAW said that the calendar had been under discussion at the Astronomical Union of the International Research Council at the meeting at Rome in May of last year. The details are given in the *Proceedings* of the Astronomical Union for 1922. It had not penetrated very far in scientific circles. The proposals involve three points: firstly, to adopt fifty-two weeks plus one or two days; secondly, to place the beginning of January at the present 22nd December; and thirdly, to have four quarters of 91 days each, two months of 30 and one of 31 days. It was interesting to notice that the scheme was delayed owing to a mistake in the day of meeting. Some time ago with Col. Gold's assistance he had compiled a calendar for meteorological purposes and for the information of people who keep self-recording instruments. That is the real crux of the situation. Self-recording instruments can only have one calendar—365 days in the year or 366 in leap year. The unit of measurement is the mean solar day. These two items of the calendar are indispensable—the day and the year. For any meteorological purpose nothing further is necessary: you can write the date of to-day as 1923, 52, and so on; with practice one would know by the number of the day where one was in the course of the year. The proposed alternative of counting by weeks is difficult—counting from the solstice the *n*th day in the year would vary by one space, two spaces, up to seven spaces. To examine the question of the occurrence of sudden variations of temperature such as Buchan used to describe, you would get these spread out over your weekly statistics, and would be lost. As far as meteorology is concerned, time as measured by the year and the day is sufficient. When you want to bring the year into relation with the month, things get extremely difficult, since the year is 365 days and the month is 29½ days. The year must have 12½ months. Sir Napier Shaw had sympathy with those who claimed to go by the moon. Before the days of printing it was the only means of identifying one's place in the calendar. By looking at the moon you could say it is the 7th day of the month ; it is a calendar hung up in the sky and one which costs nothing. He did not believe the moon was now necessary to the calendar. Dividing into months now causes confusion. We had a different method of dividing our year into the spaces of time necessary for statistics, so that what he wished to say, so far as meteorology is concerned, is that the moon is only useful for enabling people to read their thermometers in the screen at night without artificial light. The best plan would be to use only two units of time, the year of 365 days for three years and 366 for the fourth year, omitting the 366th day once a century. He did not think we need spend too much trouble over the months, but if we must have months let them be true months, so that a sight of the moon will tell us roughly our time in days from new moon, which could be assigned beforehand to certain days of the year. Our 365 days can be employed as units without doing violence to any prejudices.

Col. E. Gold did not think Sir Napier Shaw's proposal was practical from the point of view of meteorology. Meteorologists collected much information, and it was up to them to digest it ; and whether they adopted as a unit of time the week or month they must adopt some unit of time between the year and the day, and not expect people to digest 365 figures for each year. He had not seen the publication to which Sir Napier Shaw referred. But it certainly ought to be circulated more widely than it apparently had been if it was to have any chance of success. He did not quite see why the beginning of the year needed moving to 22nd December.

THE CHARACTERISTICS OF THE ATMOSPHERE UP TO 200 KILOMETRES AS INDICATED BY OBSERVATIONS OF METEORS.

By G. M. B. DOBSON, M.A., Lecturer in Meteorology, University of Oxford.

[A Lecture delivered before the Royal Meteorological Society, March 21, 1923.]

SINCE the beginning of the present century, exploration by means of kites and balloons has increased our knowledge so rapidly that it may be said that we now know the general characteristics of the atmosphere up to about 20 km. with very fair accuracy. About 20 km., however, our information practically ceases, and there seems, at present, very little hope of getting any direct observations above, say, 25 or 30 km. To obtain further information about the atmosphere above these heights, one must, therefore, look around for more or less indirect methods. There are various phenomena which occur at these altitudes which might conceivably indicate the conditions of the atmosphere, such as auroræ, meteors, night-luminous clouds, etc. We shall discuss here the information which it is possible to obtain from observations of meteors.

Before we can obtain any knowledge about the state of the atmosphere through which the meteor passes, it is necessary to consider in detail the physical processes which take place. This detailed physical investigation has been worked out by Prof. Lindemann, and is given in a paper in the *Proceedings* of the Royal Society,[1] and time only allows a general summary of it here, in order that the meteorological aspects of the results may be more fully reviewed.

There is not much difference of opinion, nowadays, as to what a meteor is. A particle of matter moving round the sun at a high speed suddenly strikes the earth's atmosphere. Owing to its great velocity it is heated in passing through the air, and gives out light. The composition of the original meteor can only be guessed from those which fall to the ground. These consist largely of a stony substance with a mixture of iron or nickel in various proportions, while some vary from nearly pure stone to nearly pure iron. Stony meteors seem to be about ten times as numerous as metallic ones. It is possible that some of those which never reach the ground have a different composition, but it can be shown that even so the final results will not be greatly affected. We shall suppose, therefore, that meteors are largely stone with a little iron. The measured velocities of meteors through the air range from about 12 km./sec. to 100 km./sec. or more. Such velocities are, of course, much greater than the velocity of sound in air, or the velocities of molecules.

On first entering the atmosphere the meteor probably strikes molecules of the air directly. It can be shown that the impact of a molecule at such a velocity will break up the atoms, and nearly all the energy will be used up in this way or lost as radiation. Very little energy will be available for heating the meteor itself, and the meteor will remain invisible. As the meteors come lower down into air of greater density, many of the molecules which have struck the meteor will be unable to get away without colliding with other molecules, before they get out of the meteor's path, and a cap of compressed gas will be formed in front of the meteor. Once such a cap is formed the pressure in it will be high, for the same reasons that it is high in the open tube of a Dines anemometer. Moreover, it can be shown that the pressure at these very great velocities is in this case also given by

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[1] *Proc. R. Soc.*, **102** (ser. A), 1922, p. 411.

$$p = \tfrac{1}{2}\rho v^2,$$

where ρ is the density of the air and v the velocity. The air in the cap has thus been greatly compressed and therefore its temperature is very high (usually between 2000° *a* and 4000° *a*). The meteor is, of course, heated by contact with this hot gas, and finally reaches a point when it begins to volatilize. It will be shown that the solid particle forming ordinary meteors has a diameter of a millimetre or so, and would be too small for the glowing solid to give much light. The light is given out when the vapour of the meteor and the air molecules collide. At the high velocities with which we are dealing most of the energy of the meteor will be converted into visible radiation. This at once gives a means of finding the mass of the original solid particle, since we can observe both the brightness and velocity. From such observations we find, as stated above, that an ordinary meteor has a diameter of the order of a millimetre. Fireballs and the like are, of course, much larger.

The energy required to heat the meteor up to the vaporizing point, and to vaporize it, must come from the work done by the meteor in passing through the air. Since, as stated, the pressure on the front of the meteor is given by

$$p = \tfrac{1}{2}\rho v^2$$

the work done per second will be given by

$$w = \tfrac{1}{2}\mathrm{S}\rho v^3,$$

where S is the cross-section of the meteor. The fact that this expression involves the density of the undisturbed air allows us to calculate this density. But it is first necessary to find how much of the total energy available actually goes to heat the solid particle of the meteor, first to raise its temperature to the vaporizing point, and then to supply the latent heat of vaporization. Obviously in the case of slow meteors the temperature may be so low that the meteor never reaches the vaporizing temperature, while in the case of fast meteors the layer of compressed gas in front of the meteor will be relatively thick and so retard conduction of heat. Thus one might expect, as one actually finds from exact calculation, that there is a certain velocity at which the proportion of the total heat reaching the meteor is greatest.

When this heating factor is known we can calculate at once how quickly a meteor will heat up to the vaporizing temperature at which point it will appear. We may turn the formula round so as to give the density at the height of appearance in terms of the observed characteristics of the meteor, when we obtain in C.G.S. units

$$\rho_a = 4{\cdot}85 \times \frac{\rho_m{}^{\frac{2}{3}}\mathrm{T}_1\mu q\mathrm{M}}{\mathrm{R}\theta} \times \frac{\Delta h\mathrm{B}^{\frac{1}{3}}\mathrm{D}^{\frac{2}{3}}}{\kappa\mathrm{L}^{\frac{1}{3}}v^3},$$

where ρ_a = the density of the air at the height of the meteor's appearance,
ρ_m = the density of the meteor,
T_1 = the vaporizing temperature of the meteor,
μ = the specific heat of the meteor,
B = the brightness of the meteor,
L = the length of path of the meteor,
v = the velocity of the meteor,
D = the distance of the meteor from the observer,
Δh = the difference in height of appearance and disappearance,
g = acceleration due to gravity,
M = molecular weight of the air,
R = gas constant,
θ = the temperature of the air,
κ = the proportion of the total energy which goes to heat the meteor.

Now all the quantities in this formula can be observed or can be estimated with sufficient accuracy except the temperature of the air. But fortunately, whatever value of the temperature is used, the same lapse-rate of density will be found, and from this we may obtain the true temperature.

In an exactly similar way we may obtain a formula for the density at the height of the meteor's disappearance—*i.e.* when enough heat has been supplied to evaporate it completely.

$$\rho_d = 14{\cdot}5 \times \frac{\rho_m^{\frac{2}{3}} l g M}{R\theta} \times \frac{\Delta h\, B^{\frac{1}{3}} D^{\frac{2}{3}}}{\kappa L^{\frac{1}{3}} v^3},$$

where, in addition to the symbols used above,

ρ_d = the density of the air at the height of disappearance,
l = the latent heat per gram of the meteor.

Space prevents a full consideration here of the numerous points and assumptions which should be considered in obtaining the above fundamental formulæ, and the reader must be referred to the paper mentioned above, where they are dealt with in detail. We therefore now pass to the meteorological results which may be obtained.

A very large number of meteors have been observed, and the results published by Mr. W. F. Denning are available for the calculation of the density of the air. The results of such a calculation are shown in Fig. 1, where the scale of densities is logarithmic. The crosses refer to densities obtained from the heights of appearance, and the dots from the heights of disappearance. (The light dots and crosses refer to less reliable observations.) In calculating the densities shown in this diagram the constants used are those for nitrogen. If, say, hydrogen is predominant at the greater heights the densities must be divided by about three, since the molecular weight is $\frac{1}{14}$ and the heating factor about $\frac{1}{5}$ that for nitrogen. This corresponds to moving the points in the diagram 4·5 mm. to the left. Similarly, if helium is predominant, the results must be divided by about 10, which corresponds to a shift of 9·5 mm. to the left. Since the formulæ involve the cube of the meteor's velocity, and since this cannot be observed with any great accuracy, one would expect the points on the diagram to be very much scattered. However, the very large changes of density with height make it possible, even from such admittedly rough data, to draw several deductions which we may now review.

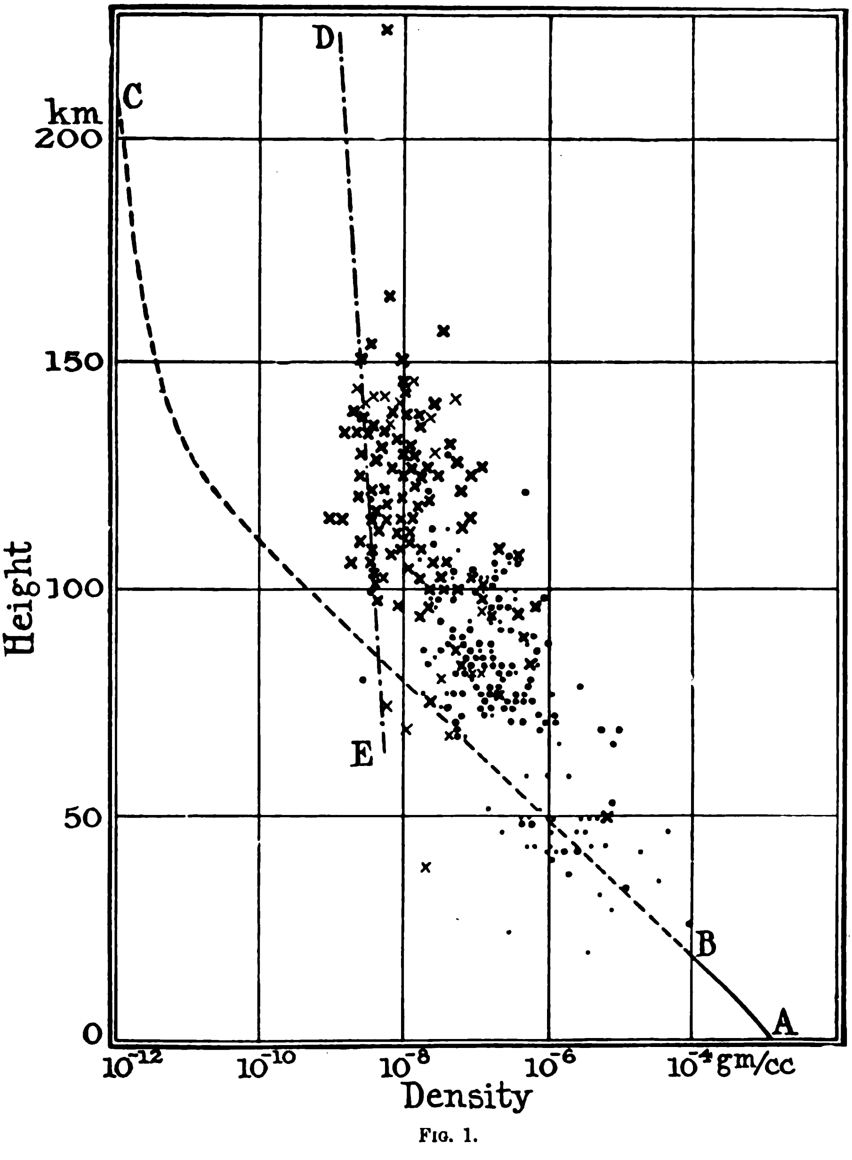

Fig. 1.

The line AB in Fig. 1 shows the density as found from *ballon sonde* observations, and the dotted continuation BC the estimated density, assuming (1) a uniform temperature of 220° *a*; (2) the proportion of helium at the surface to be 4×10^{-6}; (3) no hydrogen being present; (4) while mixing by convection is assumed to stop at 20 km. (The change of slope of the line in the upper part is due to the predominance of lighter gases.) It will be seen that

(1) The densities obtained from meteors indicate a continuation of the temperature of 220° *a* up to 50 km.

(2) There are very few meteors which appear or disappear between 50 and 60 km.

(3) Above 60 km., where there are numerous observations, the densities calculated from meteors are much higher than those given by the dotted line, and the lapse-rate indicates a temperature much above 220° *a*.

(4) The high temperature in an atmosphere predominantly nitrogen is continued up to about 160 km., above which some rather doubtful observations indicate the presence of a lighter gas. (See discussion of this on page 162 *et seq.*)

Some other independent confirmation of these rather unexpected results is much to be desired. Fortunately, several are possible: firstly, we have said that the cap of compressed gas in front of the meteor forms when a certain density is reached, depending on the size and velocity of the meteor. Before this cap forms, the meteor would not get appreciably heated, and therefore the height of appearance must be lower than the height of formation of the cap. If we calculate from the observations of meteors the density at the formation of the cap, this must give a lower limit to the density at the height of appearance. The density at the formation of the cap plotted against the height of appearance is shown in Fig. 2. The constants used are again those for N_2; if at any height hydrogen is predominant, these densities must be divided by about two. For helium they are practically correct. The mean line DE is reproduced again in Fig. 1. It is seen that densities less than 10^{-9} gm./c.c., which are often assumed, are quite beyond the limit set by this line, while the meteor results agree well with it.

Again, the supposition of a high temperature above 60 km. provides the only explanation yet put forward for the remarkable minimum in the curve of frequency of disappearance at a height of about 55 km. (See Fig. 4.) In this case the minimum is regarded as due to the sudden decrease in the rate of heating of the meteor as it passes out of the warm atmosphere into the colder one. Lower down, the increase in density will compensate for the lower temperature.

Mr. F. J. W. Whipple has pointed out that a warm layer above 60 km. would satisfactorily account for the zone of sound which usually occurs outside a zone of silence which is generally found around large explosions. The sound received in the outer zone is assumed to be refracted down from the warm layer.

If the eye observations of the slowest meteors could be relied upon, they would be excellent proof of a high air temperature. We have seen that the temperature of the compressed gas in the cap in front of the meteor depends on the initial temperature of the air and the velocity of the meteor. From the known composition of meteorites it is unlikely that meteors would evaporate appreciably at a temperature less than about 2000° *a*. From this it follows that if the air temperature were

220° *a* no meteor should appear which had a velocity less than 19 km./sec., while if the air temperature were 300° *a* the limit would be reduced to 12 km./sec. At heights below 60 km. or 70 km. this argument is not valid, since in the case of iron meteors an appreciable amount of heat may be supplied to the nucleus by oxidation. It will be seen from Figs. 3 and 4 that many meteors at heights of about 100 km. have velocities which are estimated by the observers as well below 19 km./sec., and thus indicating a higher temperature. It must be

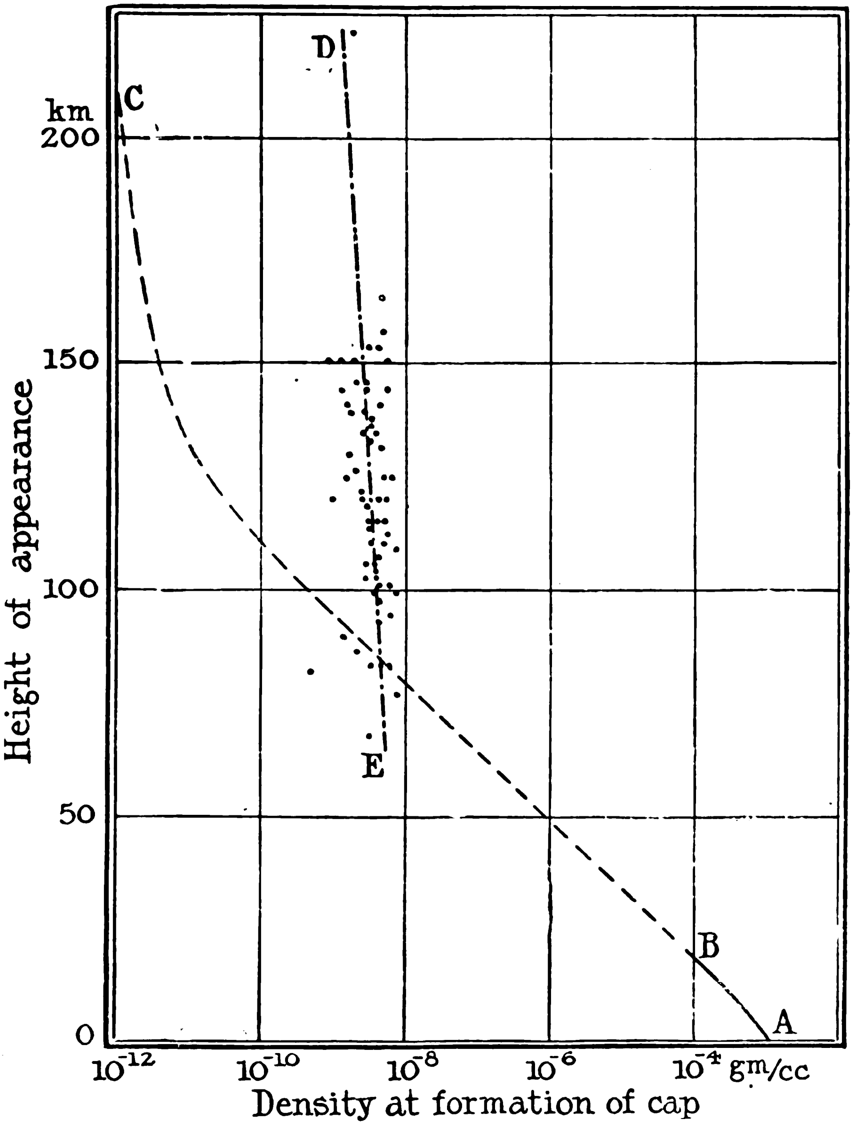

Fig. 2.

remembered, however, that it is extremely difficult to obtain a meteor's velocity accurately by eye observations.

If, disregarding the independent checks we have just discussed, we still remain sceptical, and endeavour to find an error in the main calculation of densities, the first doubtful point one might consider would be the head resistance of the meteor, which has been shown to be $\frac{1}{2}S\rho v^2$.

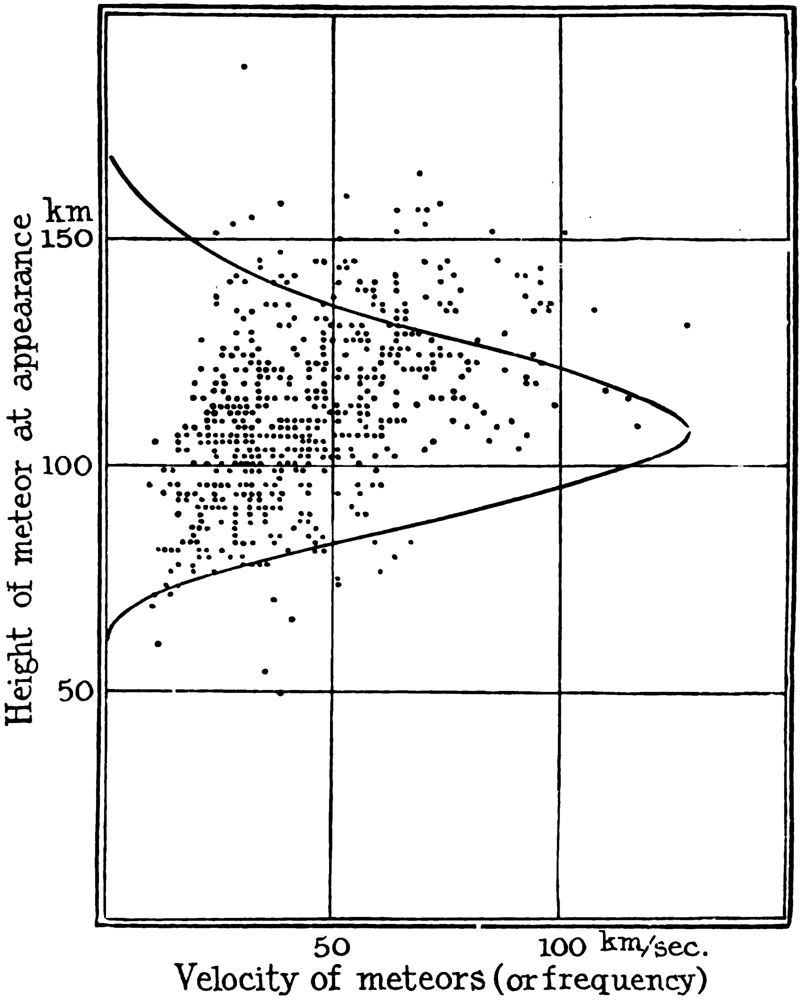

FIG. 3.

If an appreciable amount of air can flow round the meteor without being accelerated to its full velocity a lower pressure would result. Such indeed is the case with the most rapid projectiles for which results are available. However, at the very high velocities of meteors such an effect is likely to be small, and indeed, so far from making the densities as calculated from meteors agree with previously accepted views, it would make the disparity worse.

Again, it is assumed that nearly all of the kinetic energy of the meteor is finally radiated as visible light, and on this assumption the mass of the meteor is deduced. Here again a modification of the assumptions is of no avail, since if only a fraction of the meteor's kinetic energy is radiated the mass must be greater, and the resulting calculated air density would be greater.

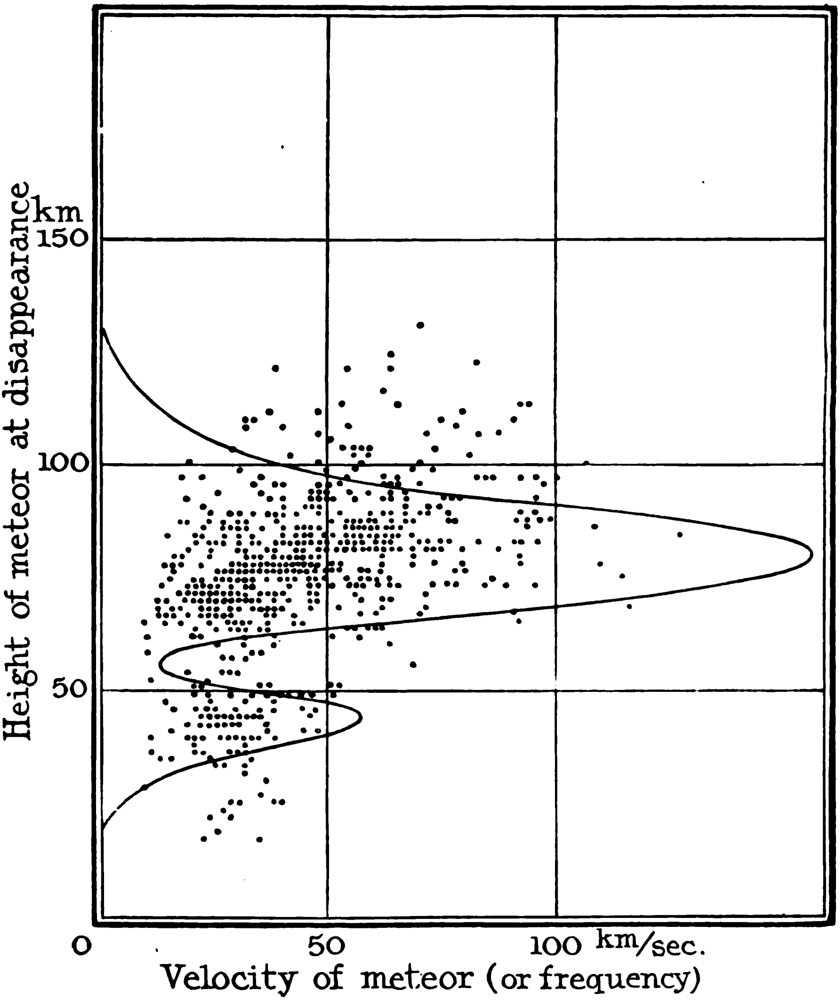

FIG. 4.

The most uncertain point in the calculation is the amount of the meteor's total energy which goes to heat and evaporate the meteor. In the case of an iron meteor, or one composed of any oxidizable material, a certain amount of heat may be obtained from oxidation. This amount will be negligible compared with the meteor's total energy, but may materially increase the rate of heating or evaporation of the meteor. This effect will be chiefly important low down, and of course cannot come in at all in the case of stony meteors, which appear to be greatly predominant. By far the strongest argument that the value used is approximately correct, is obtained from the agreement of the densities deduced from the lowest meteors with those obtained from *ballon sondes*. Indeed, since there appears to be no reason why the relative amount of heat reaching the meteor should change with height, one might quite legitimately have obtained the value empirically in this way. (See also (3), page 162.)

Let us now turn to the question of why the air above 60 km. should be warmer than that below. The generally accepted view of the origin of the low temperature of the stratosphere may be put briefly as follows: A solid body or gas which is "grey" (*i.e.* which absorbs radiation of all wave-lengths alike), if exposed only to continuous sunlight at the earth's distance from the sun, would obtain an equilibrium temperature of about 280° *a*. If the same body were placed some little distance above the earth, it would be shielded from sunlight on the average for half the time, but this loss of energy would be exactly balanced by the radiation received from the earth, and it would again have a temperature of about 280° *a*. Suppose now an imaginary body which can only absorb or radiate energy in the infra-red. In this case it absorbs practically no sunlight, but only the earth's radiation, while, since its temperature is low, it radiates as before. Thus its equilibrium temperature will be lower, and in the neighbourhood of 230° *a*. The atmosphere can absorb and radiate infra-red radiation, since it contains water vapour and carbon dioxide, but is nearly transparent to visible light. Carbon dioxide is a heavy gas, and so will soon settle out of the atmosphere and will be almost non-existent at heights above, say, 60 km. Owing to the very low temperature at the bottom of the stratosphere the water vapour there is small, and at greater heights the absolute amount will be still smaller though the relative amount will increase somewhat. On the other hand, the highest atmosphere is exposed to the extreme ultra-violet radiation from the sun. Now, as any one who has used a quartz mercury-vapour lamp will have found, ozone is formed from oxygen under the influence of radiation of very short wave-length, and we should therefore expect it to be found in the highest parts of the atmosphere where any oxygen exists. Ozone absorbs energy both in the infra-red and also in the ultra-violet, so that it can absorb some of the sun's radiation. Actually it absorbs practically *all* the sun's radiation of wave-length shorter than 3000 Å, for the solar spectrum as measured on the earth's surface ends abruptly here. The limit is so abrupt that the solar energy received on the earth at 2900 Å is only about 10^{-5} of that at 3150 Å, whereas Fabry and Buisson found that outside the earth's atmosphere the ratio would be about $\frac{1}{5}$th. The enormous reduction of the energy of the shorter wave-length by the earth's atmosphere is due to ozone. If the sun were a "black body" radiator at a temperature of 6000° *a*, then something like 5 per cent of the total energy would be absorbed by ozone. If, as seems probable, a considerable part of this absorption takes place high up, it will raise the temperature of the air much above that of the stratosphere, and a temperature of 300° *a* or so is quite likely.

If the high temperature is due to ozone we should expect it to fall again at such great heights that the amount of oxygen is negligible.

Unfortunately meteor observations cease at too low a height to show this.

If we accept the theory that the temperature of the air above 60 km. is high because it absorbs some solar radiation, we should expect a much greater annual range of temperature above 60 km. than that found in the stratosphere. Such an annual range of temperature must cause an annual variation of pressure at great heights. This annual temperature and pressure variation should slightly affect meteors, but in most cases the expected effect is too small to be seen. In two cases the results we should expect from the annual variation seem to be fully confirmed.

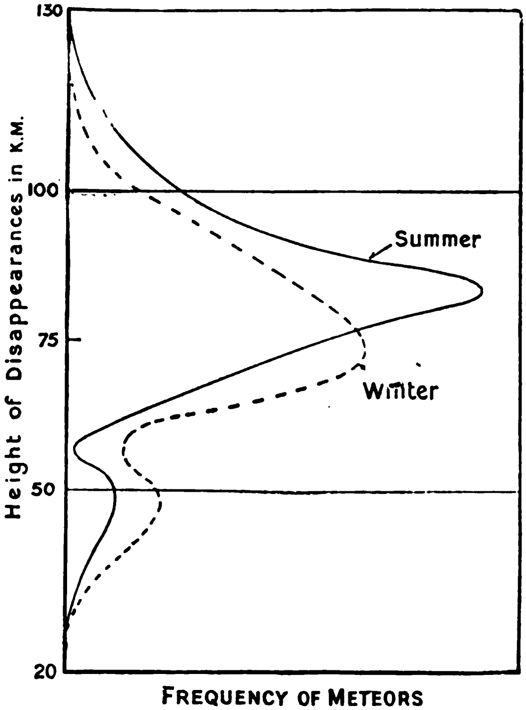

Fig. 5.

The cause of the minimum in the curve of frequency of disappearance of meteors at various heights was traced to the difference of temperature of the air above and below 55 km. When the difference of temperature is large, the minimum should be well marked, and *vice versa*. Fig. 5 shows the frequency curve for summer and winter meteors, and the expected effect is found to exist. It should, however, be noted that one or two extra meteors about 55 km. would change the appearance of the curves at the minimum considerably. (The difference in height of the main maxima is fully accounted for by a difference in average velocity of summer and winter meteors.)

We have previously referred to Mr. Whipple's suggestion that the zone of sound outside the zone of silence, which is found around most large explosions, is due to refraction of sound at the lower surface of the upper warm layer. If this is so, the silent zone should be larger in winter than in summer, and may indeed be so large in winter that sometimes the sound which should be received outside it is too faint to be noticed. This may be the cause of the marked annual variation in the audibility in England of gunfire from Flanders during the war.

One would expect the height at which auroræ are most frequent to be governed by the pressure at the level in question rather than by the height above the earth. If there is an annual variation in pressure it would probably be shown in an annual period in the height of maximum auroral frequency. Most of the measurements of auroral heights have so far been made in the spring, so that no data are available to verify this. Auroræ cannot be seen in summer owing to the bright twilight throughout the night, but it is to be hoped that observations may soon be made in the autumn and winter, when this effect may be tested.

In conclusion, let us see how the characteristics of the atmosphere obtained from meteors compare with other estimates of the composition and densities at great heights. It has already been pointed out that practically all previous estimates have been based on a uniform temperature of about 220° *a* at all heights above 11 km. The differences between the various estimates of density are due almost entirely to the various proportions of hydrogen or other light gases which are assumed to occur in the atmosphere. While the amount of helium in the lower air can be fairly definitely measured, and is equal to 4×10^{-6} by volume, there is great uncertainty about the amount of hydrogen. A minor factor is the height at which mixing by convection ceases. The dotted lines in Fig. 6 show the various estimates of densities at different heights.

Recently there has been a tendency to accept the view that there is little or no hydrogen in the atmosphere. It is unnecessary to go into the arguments for this, as they are already summarized in the *Journal* by Chapman and Milne.[1] The results obtained from meteors might at first sight appear to indicate a large amount of hydrogen, though we shall show that this is probably illusory.

Several points must be borne in mind. (1) The densities as plotted in Fig. 1 are calculated assuming the constants for nitrogen, since this is certainly predominant below 100 km. If hydrogen should predominate at any height all the densities obtained from meteors at this height should be divided by about three—*i.e.* the points should be moved 4·5 mm. to the left.

(2) Further, since the lapse-rate of density is small in hydrogen, the density, when the cap forms in front of the meteor, may not be "small" compared with that when the meteor appears, as is assumed in the calculation. If this were so, the calculated values would be too small.

(3) Moreover, it has been assumed that the meteor is spherical, and any departure from the sphere will make the calculated density too high. It is possible that a factor of a half or a third ought to be added to allow for this—especially in the values of ρ_a. It seems that a correction of this nature is required when we consider the density at about 60 km. We have said that the minimum at 50 to 60 km. in the curve of frequency of disappearance is probably due to a transition from low to high temperature. If we regard the temperature as about 220° *a*

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[1] *Q.J.R. Meteor. Soc.*, **46**, 1920, p. 357.

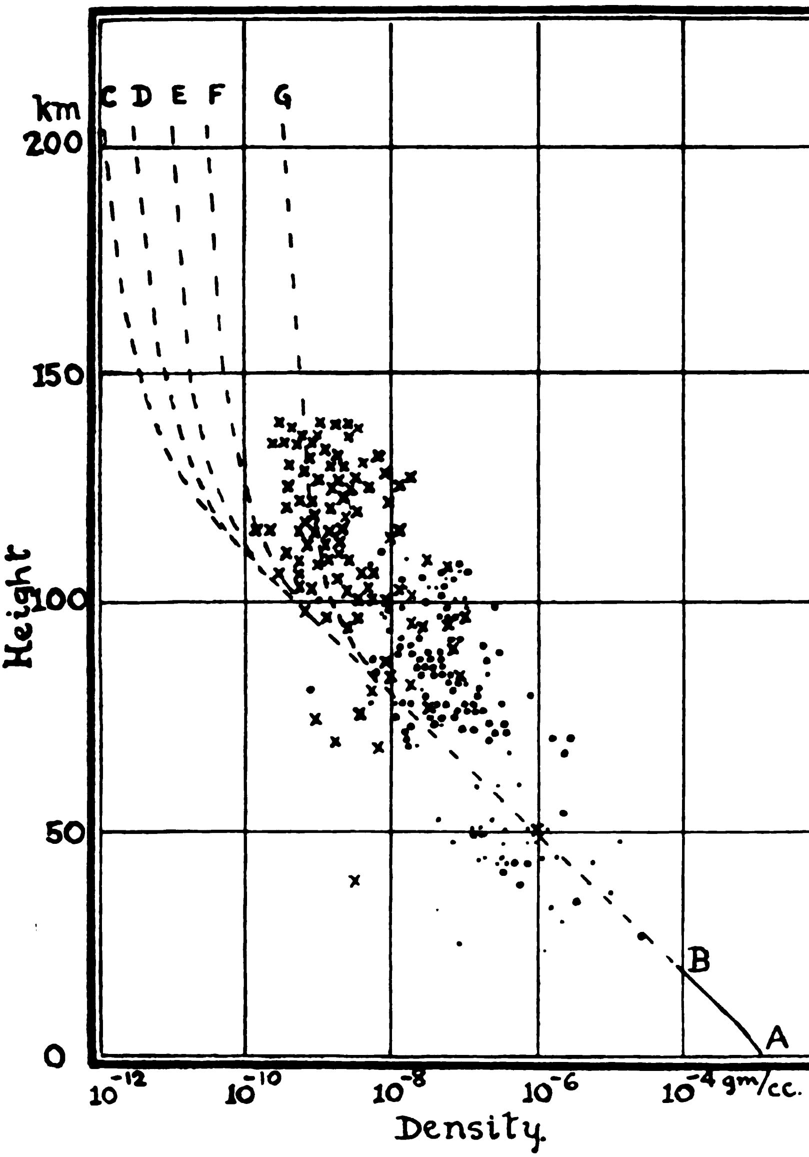

FIG. 6.

BC = calc. density assuming $H_2=0$ and mixing stops at 20 km.
BD ,, ,, $H_2=0$,, ,, 12 km.
BE ,, ,, $H_2=10^{-5}$,, ,, 20 km.
BF ,, ,, $H_2=10^{-5}$,, ,, 12 km.
BG ,, ,, $H_2=10^{-4}$,, ,, 12 km.
All assuming temperature = 220° a. All assuming helium = 4×10^{-6}.

up to 60 km. we should find a density of 2×10^{-7} gm./c.c., whereas the value given by the points on Fig. 1 is about 8×10^{-7}. It may be said that the values below 50 km. are in good agreement with the results for a temperature of 220° *a*, and the addition of a factor of a third or so would destroy this agreement; but the points are not sufficiently well grouped to allow any great accuracy, and it must be remembered that when we are dealing with the lowest observed meteors we are likely to have unwittingly selected those which are erroneously estimated at too low a height. Thus, if all the values were to be divided by, say, three, it would not destroy the agreement below 50 km., while it would make the result at 60 km. accord with a value which would be expected. It is therefore probable that all the meteor densities calculated from purely physical reasoning should be divided by about three—*i.e.* moved to the left by some 4·5 mm. in Fig. 1.

(4) It was pointed out in the original paper that the calculated values of ρ_a (see page 154) may be somewhat too large, since meteors will not be heated uniformly throughout, at the time the outside first reaches the vaporizing temperature. It was suggested that these values might be about twice too large from this reason.

(5) Finally, it must be remembered that heights of appearance are less accurately observed than heights of disappearance, partly because of the greater height, but chiefly because the meteor appears in an unexpected place, and the exact position of appearance must therefore be much less accurately observed than that of disappearance. Now, as in the case of the lowest meteors, all those meteors which appear near the upper limit are likely to be erroneously high. The upward bend on the curve of densities about 130 km. may be due to this cause. That this really is the case is made still more probable when one notices that a similar but smaller upward bend occurs if the values of ρ_d alone are taken, but this time at a lower height. For this reason it is suggested that the values above 130 km. are too high and no real change in the lapse rate of density actually occurs.

The values shown in Fig. 1 have been replotted in Fig. 6, applying the corrections suggested above, and meteors appearing above 140 km. or disappearing above 110 km. have not been used.[1]

Let us now return to consider the composition of the atmosphere as indicated by the meteor results. If the smaller lapse rate of density about 130 km. is real, it can hardly be explained otherwise than as due to the predominance of hydrogen above this height. The increase in the minimum velocity at which meteors appear, at heights above 100 km. (see Fig. 3), might be taken as another indication that the atmosphere is chiefly hydrogen above this height. The values would lead to a proportion of hydrogen at the earth's surface of 10^{-4}, which is much above the values found in the best determinations. It might perhaps be argued that the hydrogen is largely produced by volcanoes, and goes straight up to great heights in large masses without much mixing with the air. From these great heights it would slowly diffuse down, but might be prevented from reaching the ground by oxidation, say, in the ozone layer. Such an explanation would, however, seem somewhat improbable.

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[1] The density lapse rate given in Fig. 6 would lead to a temperature of about 350° *a*. In the previous paper it was stated that the radiation equilibrium temperature for ozone would be about 280° *a*. This estimate was based on results which, from the most recent measurements by Fabry and Buisson, now appear to be erroneous, and the equilibrium temperature should be much higher.

A strong argument against a large amount of hydrogen being present may be found since the decrease in velocity of the meteor when it has reached a given density is inversely proportional to the molecular weight of the gas through which it has passed, and it can be shown if hydrogen were predominant, say above 100 km. (where the density is about 10^{-8} gm./cc.), all meteors except quite large ones would have been greatly decelerated before they reached this level. The fact that many meteors have nearly the maximum velocity possible for a component of the solar system indicates that no such deceleration actually occurs.

On the whole, it seems more likely that the decreased lapse rate high up is fictitious, and that nitrogen and oxygen are the chief gases up to the greatest height at which meteors appear. The upper limit to the height at which meteors appear is probably fixed by the density at which the cap of compressed gas forms.

If our results above 140 km. are untrustworthy it follows that we have no information above this height, but it seems probable that the same lapse rate would continue until the amount of ozone (which would be formed from the oxygen present) was insufficient to maintain the high temperature in the presence of the existing amount of water vapour. About this height the temperature would gradually fall to something like 220° *a*, and the density lapse rate would continue at the value appropriate to nitrogen at that temperature, until helium became predominant at a height of perhaps 200 km. if the amount of hydrogen is negligible.

[NOTE.—Figures 1 to 5 are reproduced by kind permission of the Royal Society.]

The PRESIDENT (Dr. C. Chree), in introducing the lecturer, said that Mr. Dobson was one of the numerous meteorologists who had once worked at Kew Observatory. Since then he had taken up the study of the upper atmosphere, in which his researches were well known.

In moving a vote of thanks, Dr. CHREE expressed a hope that Mr. Dobson's references to the importance of knowing auroral heights at different seasons of the year would be noted by those engaged in auroral work. Aurora was seen in Britain at all seasons except midsummer. Mr. Dobson certainly had not exaggerated the limiting height of aurora; Prof. Störmer had observed one height of 750 km. and several exceeding 600 km. The Society was much indebted to Mr. Dobson for an interesting and suggestive lecture.

The Cup Anemometer in Canada.

Measurements of wind for the purposes of the daily weather services of Canada and the United States are taken from the indications of a cup anemograph of special design.

Mr. J. Patterson of the Meteorological Office, Toronto, has forwarded a preliminary report of experiments upon various aspects of the behaviour of the cup anemometer in the current of air of a wind-tunnel, the use of which was placed at his disposal by the authorities in Applied Science in the University of Toronto. The tunnel was operated by Mr. J. H. Parkin and his assistants: it gave wind velocities between 14 mi/hr. and 33·3 mi/hr. Before the observations were completed the tunnel had to be dismantled to be re-erected in a new building. Anemometer systems of two, three, four, five, and six cups were tried. All had factors that did not differ much from one another for the same wind velocity; but the three-cup system was the most constant, and gave a slightly better factor than the four-cup. The completion of the inquiry has to await the results of some further experiments; but, as the result of the investigation so far, the official anemometer of the Canadian Meteorological Service is being re-designed. The new pattern is to have three cups instead of four, and a factor that will correspond more closely with the actual relation between wind-velocity and cup-velocity as determined by the experiments in the wind-tunnel.

The experiments include a number of determinations of the torque on a single cup, alone and as shielded by the anemometer, stationary and revolving; the results are tested by integrating for a complete revolution.

By assuming factors for the anemometer and the consequent relation between wind-velocity and cup-velocity the resultant torque on one cup for a wind of 1 foot per second was obtained; on plotting these results and noting the areas of the positive and negative sides it was found that the two would balance if the factor for any anemometer were calculated from the equation

$$\log f = 0{\cdot}6774 - 0{\cdot}15 \log d - 0{\cdot}12 \log v,$$

where f is the factor, v the velocity of the wind in feet per second, and d the diameter of the cup in inches. This equation shows that the larger the diameter of the cups the smaller and more constant the factor. The equation should have a term to correct for the length of the arm; but it has not yet been possible to make the necessary observations. The value of f obtained from this equation agrees very well with the observed values in a three-cup system or if the arms of the cups are so long that interference does not count.

The literature concerning the factor of the cup anemometer is already voluminous; the position as regards its use for the measurement of wind in this country is set out by Mr. F. J. W. Whipple in the Reports of the Advisory Committee for Aeronautics (*Reports and Memoranda*, No. 669, January 1920). Latterly we have been specially interested in the interpretation of readings in very light winds. For us any probable deviation from the accepted value of the constant in ordinary winds has been altogether overshadowed by the question of exposure—that is to say, the effect upon the stream-lines of the air-current caused by the building and structure which carry the instrument for measuring that current.

In a very generalized sense that may perhaps be regarded as only part of the very wide question of the effect of turbulence upon the record of an anemometer. Turbulence may easily be introduced for the purposes of experiment; but it is not so easily removed from any natural wind, and its influence upon the reading is unknown.

NAPIER SHAW.

July 7, 1923.

AN EXAMINATION OF BRITISH UPPER AIR DATA IN THE LIGHT OF THE NORWEGIAN THEORY OF THE STRUCTURE OF THE CYCLONE.

By W. H. DINES, F.R.S., and L. H. G. DINES, M.A.

[Received January 24—Read April 18, 1923.]

THE following paper is based on the results of sounding balloons sent up in the British Isles between the years 1907 and 1922, and a series of kite ascents made at Pyrton Hill, Oxfordshire, previous to the war.

The available balloon ascents were 352 in number, and the first step was to prepare a list of dates and times of ascent. This list was submitted to the Director of the Meteorological Office, who kindly arranged for the corresponding synoptic working charts to be examined. The definite object of the examination was to discover on what occasions one would have expected to find a warm current overlying a cold one. There were found 16 cases out of the 352 in which such a result might be expected.

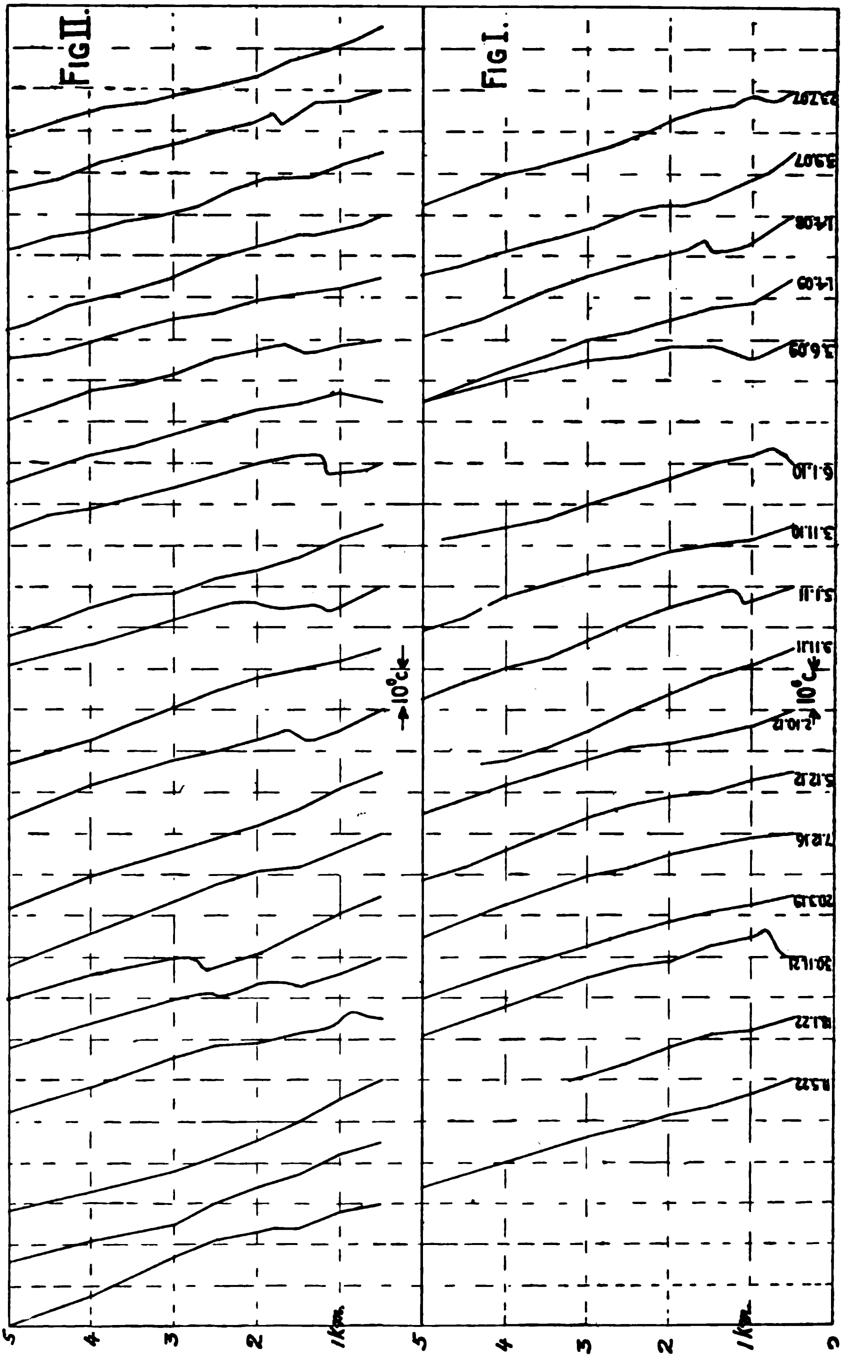
The actual report of the Forecast Division of the Meteorological Office was as follows: "We have now finished a preliminary survey of the charts on the dates of balloon ascents which you supplied. In this preliminary work we noted down all days of balloon ascents where a fairly well marked polar front was shown on the map, the ascent being in the cold sector. These are occasions on which, according to Bjerknes's theory, the balloon stood a good chance of penetrating to the warm layer above."

The lapse rate between 0·5 and 5 kilometres' height in these 16 cases was then obtained from the original notebooks and tabulated in the form of reduction of temperature below that prevailing at 0·5 km. It was thought better to use 0·5 km. as a standard instead of the ground level, in order to avoid the introduction of ground inversions, which are irrelevant to the purpose, and are due largely to quite local conditions.

The figures and dates are set out in Table I., and the lapse rates are shown plotted in Fig. I. Inspection shows that some indicate inversions of temperature and some do not; taken on the whole there are not any generally striking features about the curves.

In order to have some standard of comparison, two other groups of 20 ascents each were chosen. In the one case this was done by taking neighbouring ascents made at least a week before each of the 16, and then adding four more at random to complete the set; in the other case ascents made at least a week after were similarly chosen. By this means two sets were obtained which are definitely not associated with a polar front, but refer on the average to the same seasons of the year as the original 16. One of the sets is plotted in Fig. II.

There is a great resemblance between Figs. I. and II., and it is hardly possible to say that one possesses any characteristics not equally shown by the other. If the existence of inversions or isothermal patches be taken as a criterion, we find that they are present in 7 out of the 16; that is, in 44 per cent. In the two chance sets the percentages are 50 and 60 respectively.



In Fig. III. are shown graphs of mean values of the lapse rate in six different groups, taken in each case from the temperature at 0·5 km. as a standard. Reading from the left-hand side, the first and third curves are obtained from the two chance groups of 20; the second from 14 ascents associated with polar fronts which reached at least 4·7 km. In this group the mean pressure at sea level was 1009 mb.

TABLE I.—TEMPERATURE DIFFERENCES IN DEGREES CENTIGRADE BELOW THE TEMPERATURE PREVAILING AT 0·5 KILOMETRE HEIGHT.

Time and date of ascent.		Kilometres above M.S.L.								Place from which ascent was made.
		0·5	1·0	1·5	2·0	2·5	3·0	4·0	5·0	
h.										
16	23. 7.07	0	-1	-4	-7	-11·5	-15	-20	-27·5	Sellack.
17	3. 9.07	0	-6	-11	-12·5	-14·5	-18	-23·5	-29	Sellack.
18	1. 4.08	0	-6·5	-8·5	-9	-11·5	-14·5	-22	-29	Pyrton Hill.
17	1. 4.09	0	-6	-7	-10	-13	-15	-22	-30	Pyrton Hill.
13	3. 6.09	0	-4·5	-1·5	-1·5	-4	-5	-9·5	-15	Ditcham Park.
15	6. 1.10	0	+2	0	-3·5	-7	-10	-15·5	(-19)	Pyrton Hill.
15	3.11.10	0	-3·5	-5	-7	-9·5	-11·5	-17·5	-15·5	Pyrton Hill.
7	5. 1.11	0	-3·5	-2	-5	-8·5	-13	-20	-27	Pyrton Hill.
7	9.11.11	0	-4	-7	-11	-15	-20	-27	...	Pyrton Hill.
7	2.10.12	0	-4	-6	-8	-9	-12	-18	-25	Pyrton Hill.
7	5.12.12	0	-2	-5	-6	-8	-11	-19	-26	Pyrton Hill.
15	7.12.16	0	-1	-3	-5	-8	-10	-17	-25	Benson.
16	20. 3.19	0	-2	-4	-6	-9	-12	-18	-25	Benson.
15	30.11.21	0	+5	+3	-1	-2	-5	-12	-19	Benson.
7	18. 1.22	0	-3	-4	-7	-10·5	-14	...	...	Benson.
18	11. 5.22	0	-3·5	-6·5	-8·5	-11·5	-14	-20	-26	Benson.

The fourth is a mean derived from 20 ascents made when the pressure at sea level exceeded 1020 mb., and chosen by including all

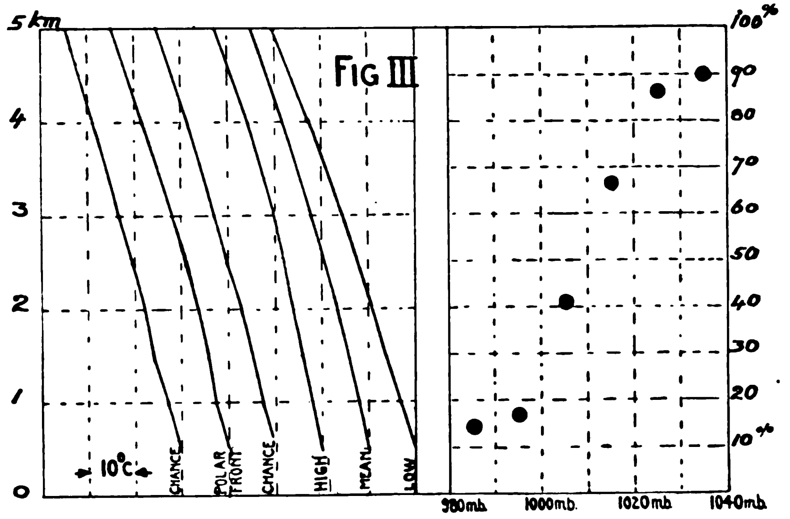


FIG III

the available cases from the year 1922, working backwards till 20 were found. The mean sea-level pressure was 1029 mb.

The fifth is formed from a very large number of ascents made in south-east England at all times of the year, and published in the

Meteorological Glossary. The sixth is similar to the fourth except that only pressures below 995 mb. were used; the mean was 987 mb. The values on which these six graphs are based are given in Table II.

Inspection of the graphs shows that the most prominent feature is the marked difference in the lapse rate as between the high and the low pressures. Above 1·5 km. the polar front group is very similar to the mean curve (No. 5); below that level it has a slightly lower rate from 1 to 1·5 km., and a higher one between 0·5 and 1 km., which is the type of variation supposedly associated with the cold current of the Norwegian theory. Unfortunately, the number of observations is not large enough to enable a conclusive opinion to be formed, for from a consideration of the 40 chance ascents it was found that the standard error due to sampling of a mean of 14 would be about 0°·5 C. at 1 km., 0°·8 C. at 1·5 km., and 1°·1 C. at 2·5 km. Without going outside these limits even it would be possible to modify the curves so that they were alike.

TABLE II.—MEAN TEMPERATURE DIFFERENCES IN DEGREES CENTIGRADE BELOW THE TEMPERATURE PREVAILING AT 0·5 KILOMETRE HEIGHT.

Ascents.	Kilometres above mean sea level.							
	0·5	1·0	1·5	2·0	2·5	3·0	4·0	5·0
Chance group of 20 ascents	0	−2·9	−5·7	−7·7	−10·3	−13·3	−18·7	−24·9
Group of 14 polar front ascents	0	−2·6	−4·3	−6·4	−9·1	−11·9	−18·2	−24·9
Chance group of 20 ascents	0	−2·4	−4·8	−7·2	−10·1	−12·8	−18·8	−25·2
Group of 20 ascents with high barometer . .	0	−2·1	−4·1	−6·1	−7·9	−10·1	−15·8	−22·8
Mean values for S.E. England	0	−2·0	...	−6·8	...	−12·3	−18·3	−25·2
Group of 20 ascents with low barometer . .	0	−3·2	−6·4	−9·2	−12·4	−15·6	−22·7	−30·5

It would seem likely on the Norwegian theory of the cyclone that inversions of temperature would tend to be more frequent when the pressure is low, and an investigation was therefore made to discover the relation between the pressure at mean sea level and the occurrence of inversions or isothermal patches between 0·5 and 5 km. Table III. gives the result, which is also shown plotted in the right-hand compartment of Fig. III. It is evident that the connection with pressure is very close indeed, but in the sense that with high pressure a temperature discontinuity of some kind is almost always found, while with low pressure such discontinuities are rare.

In the case of the 14 ascents plotted in Fig. I., which reached 4·7 km. or more, the mean sea-level pressure was given before as 1009 mb. If, then, taking Table III. as a guide, we should attempt to predict the number of occasions on which discontinuities would have been found simply on the basis of pressure, the percentage would be about 50. Actually there were 7 out of 14. (The 44 per cent previously quoted included two ascents which did not reach 4·7 km.)

The exact agreement is, of course, a chance occurrence, but it corroborates the conclusion previously suggested that the presence or absence of a polar front has a very insignificant effect on the likelihood of the occurrence of a discontinuity between 0·5 and 5 km.

A more satisfactory analysis of the 16 ascents in Fig. I. would have been possible if a knowledge of the humidity had been available. It is an integral part of the Norwegian theory that warm damp air is pushed up an inclined plane formed by colder air; in such a case high humidity must occur above the boundary. Unfortunately, the balloon meteorographs were not as a rule fitted with hygrometers, and no information is available.

There remains another source of information in the kite ascents made at Pyrton Hill previous to the year 1912. For this purpose a series of over 400 ascents, made during the five years 1907 to 1911, was taken and examined for the occurrence of inversions.

They were all relatively low ascents, mostly up to about 1·5 km. and never above 2 or 2·5 km. The humidity was somewhat crudely registered by a hair hygrometer, but though it did not give absolute values very accurately it indicated relative changes as between different layers quite definitely.

TABLE III.—PERCENTAGE NUMBER OF INVERSIONS AND ISOTHERMAL PATCHES BETWEEN 0·5 AND 5 KILOMETRES AT VARIOUS M.S.L. PRESSURES.

Pressure at M.S.L.	Percentage of total.	Number of cases.
	%	
Below 900 mb. . . .	14	21
Between 900 and 1000 mb. .	17	31
,, 1000 and 1010 mb. .	41	83
,, 1010 and 1020 mb. .	67	142
,, 1020 and 1030 mb. .	86	56
Above 1030 mb. . . .	90	19
All pressures	58	352

Among the 400 odd cases a definite temperature inversion was found in 41. It is as well to point out here that, as a kite cannot be raised without an appreciable wind, all these inversions were genuine phenomena of the free air, and inversions common in calm anticyclonic weather were automatically excluded. It is for this reason that the frequency of occurrence is so much less than in the case of the balloon ascents, where no such selective tendency operated; also in the case of the kite ascents isothermal patches were not included.

An examination of the 41 inversions showed that almost invariably a very definite and sometimes very large fall in relative humidity occurred with the rise in temperature. Only three partial exceptions to this rule were found. Of these three, one ascent made at 10 h. on February 5, 1910, had saturated conditions throughout, with an inversion of between 1° and 2° C. at about 1·1 km. above mean sea level. The surface wind was 14 m.p.h. from S by E, while at 1 km. it was 38 m.p.h. from SW; the Forecast Division of the Meteorological Office reported that at 7 h. a definite polar front extended along the line from Pembroke to Carlisle, and advanced towards the east during the day, though the line of demarcation between the two currents became less sharp. An examination of the *Daily Weather Reports* of the period shows that the weather conditions at Oxford changed from cold at 7 h. to warm by 18 h., with a wind shift from S to WSW; rain also fell in Oxfordshire to the extent of 1 or 2 mm. on the 5th.

The circumstances fit the hypothesis that this was a case of a polar front with a sloping discontinuity extending from it towards the south-east. The angle of slope cannot be accurately determined, but would seem to have been something between 1 in 100 and 1 in 200. This example is the only one which the authors have found in the records which they have investigated.

The second case referred to had a pronounced inversion at 0·4 km., with apparently only a small drop in relative humidity. No cold current existed anywhere in the British Isles at the time.

The third had a small inversion at 0·6 km. with a slight drop in relative humidity. There was a temperature discontinuity across the English midlands on that date as between two North-Easterly currents, but the ascent appears to have been made in the warmer current.

Previous to this series at Pyrton Hill large numbers of kite ascents had been made at Oxshott and at Crinan by one of the authors; many of them reached greater heights than those made later at Pyrton Hill. It was the general experience at that time that an inversion which was not definitely drier above was a very rare event indeed. So much was this the case that a note is to be found in an original notebook commenting on a certain inversion which only showed a slight decrease in relative humidity as a very unusual thing. The evidence seems clear that in south-east England at least we can hardly ever expect to find an inversion in the lower layers of the free air which is damp above.[1]

The conclusions reached in this paper are negative rather than positive, and to that extent are unsatisfactory. On the positive side, however, there emerge the following facts: (1) That the frequency of temperature discontinuities between 0·5 and 5 km. is very highly correlated with the surface pressure, an interesting point in view of the large number of variables of the upper air already known to be closely connected with the pressure. (2) Temperature inversions in the lower layers up to 2 km. which are not definitely drier above are so rare as to be almost negligible. That is, definitely warm damp currents immediately overlying cold dry ones seem almost impossible to find among the existing observations, although these amount to many hundreds.

The negative result is that the authors can find in the balloon records no distinguishing peculiarities in the upper-air temperatures on the dates given by the Forecast Division of the Meteorological Office, dates selected absolutely without bias. The list is given in Table I., and is available for further investigation by any one interested. It seems surprising that in the British Isles out of three or four hundred dates submitted to the Forecast Division so few should have been found showing decided indications of a polar front. The balloon ascents were mostly made on days chosen in advance by the International Committee, with a certain number in addition selected as occasions of very high or very low barometer. They may be treated for our purpose as random dates.

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[1] See *Nature*, **111**, 1923, p. 495.

The kite ascents were dependent on wind, and that fact cuts out a good deal of anticyclonic weather, which makes their evidence more valuable.

Some difficulty was experienced in finding a suitable criterion of a discontinuity in the sense in which it is used in the Norwegian theory. A precise definition does not seem to be available, and the authors have adopted that of the inversion or isothermal patch as the best under the circumstances. While they admit that something rather less rigorous than this might have been better, yet the very large mass of data available makes a rigorous test desirable. Even if this point be conceded, the great resemblance between the graphs in Figs. I. and II. remains, and the conclusions drawn from them are unaffected.

DISCUSSION.

Mr. S. F. WITCOMBE said Mr. J. S. Dines had asked him some months ago to undertake an exploration of the polar front with reference to upper-air ascents. The limit set by Mr. Dines was that they should not consider temperature contrasts smaller than 7° F. In locating the polar front, temperature was of primary importance, but other points equally called for consideration. Dew point was used in the early days on 7 h. maps, for which the dry- and wet-bulb readings were published. Later on dew points were obtained from the telegraphed humidity at different hours during the day. Cloud observations, which were, he supposed, one of the main ways by which one could indentify the polar front, were only available in later years. A certain importance was attached to wind direction changes, which give one a good idea of the position of the polar front. Though only 16 cases out of 352 were found which satisfied the conditions, when one considered that the temperature contrast is on an unusual scale for the British Isles the low number was not surprising. Of these 16 cases, in 8 of them the point of ascent was less than 100 miles from the polar front; in 2 of them more than 200 miles distant. It was possible that these comparatively large distances had some bearing on the negative results of the investigation. If we consider warm air pushed up a slope the rising air must at some point arrive at a temperature corresponding with that of the underlying cold air. At some distance from the front we might get a change in the lapse rate only, without an inversion. Examples of this have been found, considering only the first two months of the present year. On the 8th of February a warm sector lay to the west of Utrecht. A definite change occurred in the lapse rate at 6600 ft., with a rise in the humidity from 67 to 94 per cent. On the 16th of February at the same place, in front of a line of occlusion at 770 mb., with a change in the lapse rate the humidity rose from 65 to 85 per cent. On January 31st, at a smaller distance from the polar front, Leuchars showed above an inversion an increase to 96 per cent humidity in front of a warm sector. The slide exhibited showed the temperature distribution in the case of May 11th, 1922, when a low over France gave rise to a definite temperature discontinuity, 66 to 70° in Central France and 46 to 50° at Flushing and in south-east England. The point of ascent was some distance from the polar front. If we suppose that the rising air is cooled at a greater rate than the lapse rate for the cold air, we may find either only a change in the lapse rate or, if the initial conditions were modified, that possibly the two lapse rates were equal and that the temperature gradient might show as a continuous line.

Col. E. GOLD said that he felt very interested in Mr. Dines's discussion of the results of his investigation of the statistical basis of this interesting theory.

His explanation was perfect, his result unsatisfactory. Mr. Witcombe had put before them some of the reasons which indicated that there was a better foundation for the theory of the polar front than would appear to any one reading the paper. Probably the first thing that meteorologists would examine would be the hypothesis that there must be an inversion on passing from equatorial to polar air. There is cold air on two sides of a depression and warm air in the middle sector. As Mr. Witcombe explained, the existence of an inversion depends on the assumption that in the cold air there will be a lapse rate as great as the adiabatic lapse rate. Obviously the warm air in Bjerknes's theory is rising over the cold air, and so long as it is not saturated it has a lapse rate probably nearly double that of the cold air. Some distance away from the neighbourhood of the front the warm air, if it continued to rise, would be colder than the cold air. Actually before such a stage was reached there would be mixing, but there would be no marked inversion. If the warm air has reached saturation point, conditions are different. Mr. Witcombe had explained—and he thought it ought to be mentioned in the paper—the number of occasions on which the ascents were made in the front and in the rear of the depression. The Bjerknes diagram does not give quite the same steepness of front over the cold air in advance of the depression as over the cold air of the north-west current in the rear of the depression. Actually it might not be that shape at all; the dividing surface might be almost vertical in the rear of the warm air on a good many occasions. Thus one need perhaps not be surprised if over the cold air of the rear one did not reach any marked temperature difference below the 5 km. level indicative of a junction between the polar front and the equatorial air, unless one were close to the front itself. There was another point: Mr. Dines had both now and in *Nature* assumed that equatorial air is damp air. Although the driest air anywhere in the troposphere is over the equator, he had no doubt that "equatorial" air in these latitudes was "damp" near the surface, reckoned absolutely. It did not necessarily follow that its *relative* humidity near the surface is very high. Its moisture content is greater than that of the air of the polar front, but that does not imply a higher relative humidity near the surface, and it does not imply that above an inversion there will be increase of humidity. He had no doubt there were occasional inversions when there was an increase of humidity, but in this part of the world the air might very well be nearly saturated below the inversion. It was certain that in many cases there is saturation near the top of the cold air. The paper was undoubtedly one which ought to have been written, but he did not think the investigation was complete until there had been enough cases examined individually to enable an accurate correlation to be deduced. There was one more point connected with the chance ascents. It ought to be made quite clear that these ascents are not necessarily ascents in which there is *no* polar air. As Mr. Witcombe explained, the ascents which were selected were ascents in which there was undoubtedly polar air in the neighbourhood, but it did not follow that all the other occasions were occasions when there was no polar air.

Mr. M. A. Giblett said that his attention was attracted to a sentence, just below Table II., on which the paper seemed to be based, viz. that "it would seem likely on the Norwegian theory that inversions of temperature would tend to be more frequent when the pressure is low." He asked on what this was based, for he did not know anything in the Norwegian papers which was opposed to the frequent occurrence of inversions in anticyclones. It was well known that such occurred, and indeed they were held by many to mark places where air was gradually sliding downwards, just as in a cyclone the discontinuities of Bjerknes were surfaces of upward sliding. If this were the case it would help to explain the frequency distribution of Table III., which showed that the frequency of inversions increased with the surface pressure. Col. Gold and Mr. Witcombe had indicated how, in the case of upward sliding, there was a tendency towards obliterating an existing inversion if the lapse-rate of temperature in the cold wedge underneath were anything less than the adiabatic rate. In the case of downward sliding this effect would operate in the direction of forming or strengthening inversions.

Mr. J. S. **Dines** said that the results obtained seemed to call for some reconsideration of the polar-front theory. The most difficult part to reconcile with Bjerknes's view of the mechanism of cyclones was the fact that temperature inversions were almost always associated with a dry layer of air lying immediately above them. Although, as Col. Gold had pointed out, equatorial air was not necessarily or usually saturated at the surface, yet we must remember that Bjerknes accounted for a large part of our rainfall by the sliding of warm equatorial air over a wedge of cold polar air. On this theory, therefore, the warm air above an inversion must frequently be saturated. It now appeared that this was not the case in practice.

Note added later.—Was it possible that kites were not flown in steady rain and so missed the "warm front" inversions, encountering only what might be called non-Bjerknes inversions?

Mr. L. H. G. **Dines**, in reply, said the Bjerknes theory is dynamically based on discontinuities, and is dependent on the existence of such. It postulates also that above a certain minimum level the air above the sloping discontinuity is saturated, the saturation extending possibly to the cirrus level. The discontinuity is treated as an easily recognisable thing, not necessarily in all cases an actual inversion, but something more than mere stability in the atmosphere. If it be the cause of cyclones it would be supposed that deep ones would show the effect strongly, and that there would be a good chance of its taking the form of an actual inversion near the surface ; the remarkable thing is that this does not seem to be the case. It is necessary to explain the fact that the deeper the cyclone the less chance there is of finding a pronounced form of discontinuity.

Mr. Giblett raised the point that possibly the inversions found in anticyclones mark places where warm air is sliding downwards. It is to be noted that warm air will not slide down a slope unless there be the requisite pressure distribution to compel it to do so. This means that a suitable wind distribution must be postulated above and below the surface of discontinuity which will maintain an approximate dynamic equilibrium everywhere. It is not easy to imagine such a distribution in the quiescent conditions of an anticyclone ; there is also the observed fact that balloon records almost always show the inversion to extend simultaneously over a large stretch of country at the same height. A balloon falling 100 km. away will generally find the inversion at the same height at the place of fall as at the start.

Col. Gold suggested that except at low levels there need not, in many cases, be even a potential inversion on passing from the "cold" to the "warm" air, but this seemed to limit the scope of the theory to the lowest layers of the atmosphere, a point of view with which the speaker felt inclined to agree. With regard to the chance ascents, the point is that they were made on random dates in all classes of pressure distribution, only excluding those on which a very good chance existed of finding definite polar-front phenomena.

An important thing to notice is that the mean curve obtained from the cases of the polar front is extraordinarily like that of the grand mean of all cases, and it becomes necessary to explain why on days when warm air was supposedly lying over cold the lapse rate had almost exactly its average value. There is no doubt about the existence of special cases which seem to support the Bjerknes theory ; the speaker had found several himself. It would, however, have been supposed that so striking a theory would be easy to prove by direct observation, whereas, after dealing with many hundreds of ascents, very little of a definite nature had been found.

Mr. W. H. Dines, who was unable to be present, sent the following note:—In reply to Col. Gold and Mr. Witcombe, and in the letter to *Nature* and elsewhere, he used the terms "damp" and "dry" air as equivalent to air with a high and low relative humidity and without reference to the actual water content. He thought that "polar air" should be dry in that sense and "equatorial air" damp, but the terms "polar air" and "equatorial air" badly required precise definition. They were commonly spoken of as though one were blue and the other red and they could be distinguished from each other at a glance; whereas, if one is charged with a sin of omission or commission and convicted on unimpeachable evidence, the defence set up is that it is a case of mistaken identity.

The reply to Mr. J. S. Dines's question was that kites at Pyrton Hill and elsewhere were flown without reference to rain if the wind were suitable. So far as his recollection served, inversions shown by kite or registering balloon ascents were very rare in rainy weather.

Death of Captain C. H. Ryder.

The death took place on May 3rd of Captain Carl Hartvig Ryder, the Director of the Danish Meteorological Service. Captain Ryder was an officer in the Danish Navy, and was appointed Director in 1907; he became a member of the International Meteorological Committee in 1910, and was also a member of the International Commission for the study of the Upper Atmosphere. When serving in the Danish Navy Captain Ryder was employed on a survey of the Greenland coasts; he was interested not only in meteorological and ice conditions, but paid some attention to botanical matters and to questions of the early Danish and Norse settlements on the coasts which he visited. Though Captain Ryder made no important original contributions to the science of meteorology, yet his knowledge of meteorological matters and his sound common sense made him a very valuable member of the international committees on which he served, and his genial personality will be much missed by his colleagues of all nations; his death is a great loss to international meteorology, especially in the present rather difficult times. He had frequently visited England, and he spoke English perfectly; moreover, he entertained the most friendly feelings towards this country, which were frequently expressed in his letters.

It is announced that Dr. D. la Cour has been appointed Director in succession to Captain Ryder.

ON THE MECHANISM OF CYCLONES AND ANTICYCLONES.

By TATUO KOBAYASI, F.R.Met.Soc., Assistant Professor in the
Imperial University of Tokyo.

[Received February 15—Read April 18, 1923.]

For many years cyclones were believed to be circular vortices. But since J. Bjerknes published in 1919 his theory of polar fronts, they were considered not to be simple circular motions. In 1921, V. Bjerknes explained them as wave motion in the atmosphere. However, though most moving cyclones have pairs of polar fronts, yet many others, even very strong and long-lived ones, show no trace of the discontinuity lines of temperature, and some others have only one of these lines. Especially when the cyclones stop at one point for some time, we generally see no such line distinctly. For this reason it is natural to consider cyclones as circular motions as before, their motions being modified by the presence of polar fronts. Accordingly the existence of polar fronts is not the necessary condition for cyclones, but cyclones have polar fronts when certain conditions are fulfilled. At least, for secondary cyclones, the writer has observed in his former paper[1] that the polar fronts were only produced after the secondaries had been induced. In this paper the writer will explain his views about the formation of polar fronts and some mechanism of cyclones and anticyclones.

§ 1. The Formation of Squall Lines.

In order to express the motion of air in the whole region of a cyclone by mathematical expressions, it is necessary to make some assumptions about the distribution of wind speeds as close as possible to the truth.

Many investigations have been made on this subject, but when we observe the actual examples we find that, though the distribution is very irregular, being affected by the irregularity of the earth's surface, yet the change of the wind speed in some central part of a cyclone with distance from the centre is not appreciable. Let us call this part of a cyclone "the principal part." Moreover, the barograph records of the principal parts of passing cyclones, if not accompanied by deep troughs, have the form of hyperbolae. A hyperbola is obtained when a circular cone is cut by a plane parallel to its axis. Therefore we may consider the depression of a cyclone as a cone (excepting the part very near the centre), and the barograph records as the eccentric section of this cone. For these two reasons it seems to be very near the actual conditions to assume that the barometric gradient, and consequently the geostrophic wind in the principal part of a cyclone, is constant. As we are considering here only extratropical cyclones, the geostrophic wind will be assumed to represent the gradient wind.

The decrease of the gradient outside the principal part will vary with the surrounding conditions. Therefore, we can make any reasonable assumption for it. Here we will assume that there is neither an ascending nor a descending current of air in this region.

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[1] *Q.J.R. Meteor. Soc.*, **48**, 1922, p. 169.

Take, in a horizontal plane, a system of polar co-ordinates which moves with the translation of the centre, and of which the centre of the cyclone is the origin. Then we may consider the cyclonic system to be stationary with respect to the origin. Therefore the equation of continuity in the region where there is no vertical current is

$$\frac{\partial \dot{r}}{\partial r} + \frac{\partial \dot{\theta}}{\partial \theta} + \frac{\dot{r}}{r} = 0, \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

taking the density of the air to be constant. In investigating this equation we may leave the motion of air relative to the origin, caused by the translation of the centre, out of consideration, because a parallel motion never causes a vertical acceleration. Then $\frac{\partial \dot{\theta}}{\partial \theta}$ is zero in the case of a circular cyclone. Let V be the geostrophic wind at any point, J the ratio of the actual wind speed at a certain height to the geostrophic wind, and α the angle between these two winds. Then we may put

$$\dot{r} = -\mathrm{VJ} \sin \alpha. \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

The observations show that J and α are nearly constant for a fixed height, when the conditions of the earth's surface are the same. Therefore the condition of no vertical current is

$$\frac{\partial \mathrm{V}}{\partial r} + \frac{\mathrm{V}}{r} = 0. \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

The solution is

$$\mathrm{V}r = \text{constant.}^1 \quad . \quad . \quad . \quad . \qquad (4)$$

Let R be the radius of the principal part, and $\bar{\mathrm{V}}$ the geostrophic wind in that region. Then the following relation must be satisfied:

$$\mathrm{V}r = \bar{\mathrm{V}}\mathrm{R}. \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

And we know the relation

$$\mathrm{V} = \frac{1}{2\omega \sin \phi \rho} \frac{\partial p}{\partial r}, \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

where p is the pressure, ρ is density, ϕ is latitude, and ω is the angular velocity of the earth.

Therefore, if G be the barometric gradient in the principal region, we have

$$r\frac{\partial p}{\partial r} = \mathrm{RG}.$$

Hence

$$p = \mathrm{RG} \log r + \text{constant.} \quad . \quad . \quad . \quad . \qquad (7)$$

The constant may be determined as p is continuous at R. This equation shows that p tends to infinity at infinite distance. But this expression is applicable only to the region where there is no vertical current, and such a region cannot extend so far.

About the translational motion of a cyclonic system, whether we assume that it is carried by the general current of the higher atmosphere, or that the cyclone itself has the ability to travel, it is clear that the system moves through the general atmosphere in the lower layers. If

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[[1] Two assumptions are made here: firstly, that the geostrophic wind V is everywhere constant in the principal part, and, secondly, that the ratio J of the actual wind U to the geostrophic wind is constant. It would have been simpler to have assumed at once that U = constant defines the conditions in the principal part, and to replace equation (4) by $\mathrm{U}r = \bar{\mathrm{U}}\mathrm{R}$.—D. B.]

we neglect the general motion of the distant parts of the lower atmosphere, a cyclone has a velocity relative to the distant atmosphere equal to the translational velocity relative to the earth. Let this velocity be expressed by v. Then the relative velocity of air caused by the translation of the origin in the direction of $\theta = 0$ is

$$r\dot{\theta} = -v \sin \theta,$$
$$\dot{r} = v \cos \theta.$$

Put

$$\mathrm{JV} = \mathrm{U}. \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Then U is the wind velocity relative to the moving centre in the layer considered. Assume that J and α are constant for the whole area. Then the corresponding velocity of the air is

$$r\dot{\theta} = \mathrm{U} \cos \alpha,$$
$$\dot{r} = -\mathrm{U} \sin \alpha.$$

Therefore, the whole motion[1] relative to the earth is

$$\left.\begin{aligned} r\dot{\theta} &= \mathrm{U} \cos \alpha + v \sin \theta \\ \dot{r} &= -\mathrm{U} \sin \alpha - v \cos \theta \end{aligned}\right\} . \quad . \quad . \quad . \quad (9)$$

Then the equation of the stream line is

$$\frac{d\theta}{dr} = \frac{\theta}{\dot{r}} = -\frac{1}{r} \frac{\mathrm{U} \cos \alpha + v \sin \theta}{\mathrm{U} \sin \alpha + v \cos \theta}. \quad . \quad . \quad . \quad (10)$$

Put

$$\kappa v = \overline{\mathrm{U}}, \quad . \quad . \quad . \quad . \quad . \quad (11)$$

where $\overline{\mathrm{U}}$ is U in the principal part. Then in the region $r < \mathrm{R}$,

$$\frac{d\theta}{dr} + \frac{1}{r} \frac{\kappa \cos \alpha + \sin \theta}{\kappa \sin \alpha + \cos \theta} = 0. \quad . \quad . \quad . \quad . \quad (12)$$

The integral of this equation is

$$\log (\kappa \cos \alpha + \sin \theta) + \frac{2\kappa \sin \alpha}{\sqrt{\kappa^2 \cos^2 \alpha - 1}} \tan^{-1} \left\{ \frac{\sqrt{\kappa \cos \alpha - 1}}{\sqrt{\kappa \cos \alpha + 1}} \tan \left(\frac{\theta}{2} + \frac{\pi}{4} \right) \right\}$$
$$+ \log r = \text{constant}. \quad (13)$$

And in the region $r > \mathrm{R}$ (from 5, 8, and 11),

$$\frac{d\theta}{dr} + \frac{1}{r} \frac{\mathrm{R}\kappa \cos \alpha + r \sin \theta}{\mathrm{R}\kappa \sin \alpha + r \cos \theta} = 0. \quad . \quad . \quad . \quad (14)$$

The solution is

$$\kappa \mathrm{R} \theta \sin \alpha + r \sin \theta + \kappa \mathrm{R} \cos \alpha \,.\, \log r = \text{constant}. \quad . \quad (15)$$

Fig. 1 has been drawn from these two equations, (13) and (15), giving κ and α the following values, which are probable on the surface of the earth.

$$\kappa = 3, \quad \alpha = 20^\circ.$$

Since the motion of the air is stationary with respect to the origin, the stream-lines are at the same time the orbits of fluid particles. When we reduce these lines of flow to the co-ordinate system fixed to the earth's surface, we get the paths of air or trajectories. In Fig. 1 *b* some of the lines of flow are transformed into trajectories.

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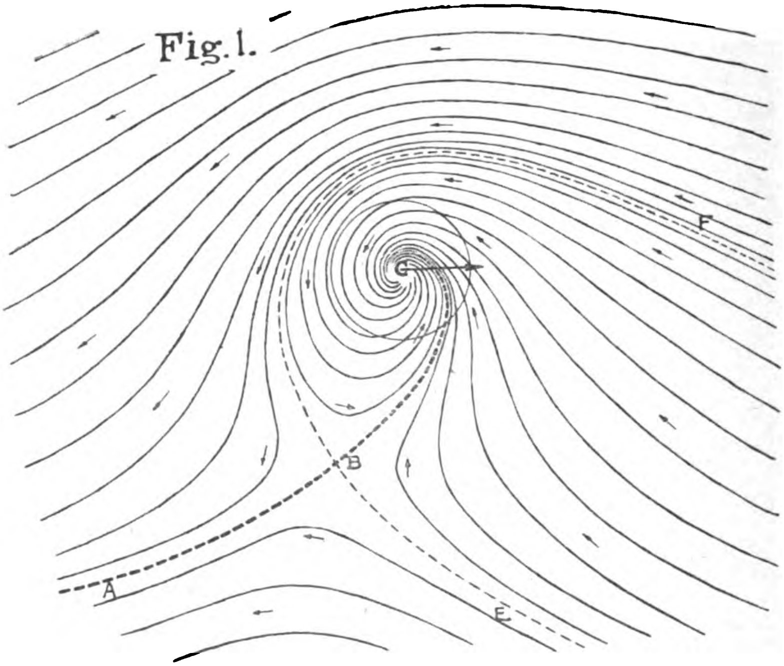
[1] In equations (9) the first terms in each component give the velocity of air relative to the moving centre. The second terms with sign changed give the velocity of a point on the earth's surface relative to the moving centre. Hence equations (9) give the velocity of the moving air relative to the earth's surface.—D. B.]

This calculation can be made only for extratropical cyclones, whose low pressure is kept up mainly by the deviating force of the earth's rotation. The tropical cyclone, whose pressure gradient is balanced by centrifugal force, must have different wind speeds on its two sides, when it travels.

The results, which have thus been obtained theoretically for motion with reference to the centre from the consideration of the travelling cyclone as a system with instantaneous circular motion and a travelling centre, may be compared with the diagrams representing the motion with regard to the centre in the cases of three cyclonic systems investigated by Sir Napier Shaw and Mr. R. G. K. Lempfert.[1]

Fig. 1.



Instantaneous lines of flow connected with the centre of a travelling cyclone.

The similarity of the lines in the case of the slow-travelling depression of November 11-13, 1901, in the neighbourhood of the singular point B of Fig. 1, is very remarkable. In this case the chart of the actual cyclone covers much the same ground as the theoretical chart. In the case of the rapid-travelling cyclone of September 10-11, 1903, the lines belonging to the region within the line of discontinuity are clearly represented, while in the other case of a fast-travelling storm the analogies are less distinct.

To obtain the diagram of Fig. 1 we have made many assumptions. But, without these assumptions, we always get the same kind of diagram, if only the following two conditions are fulfilled: 1. The wind speed

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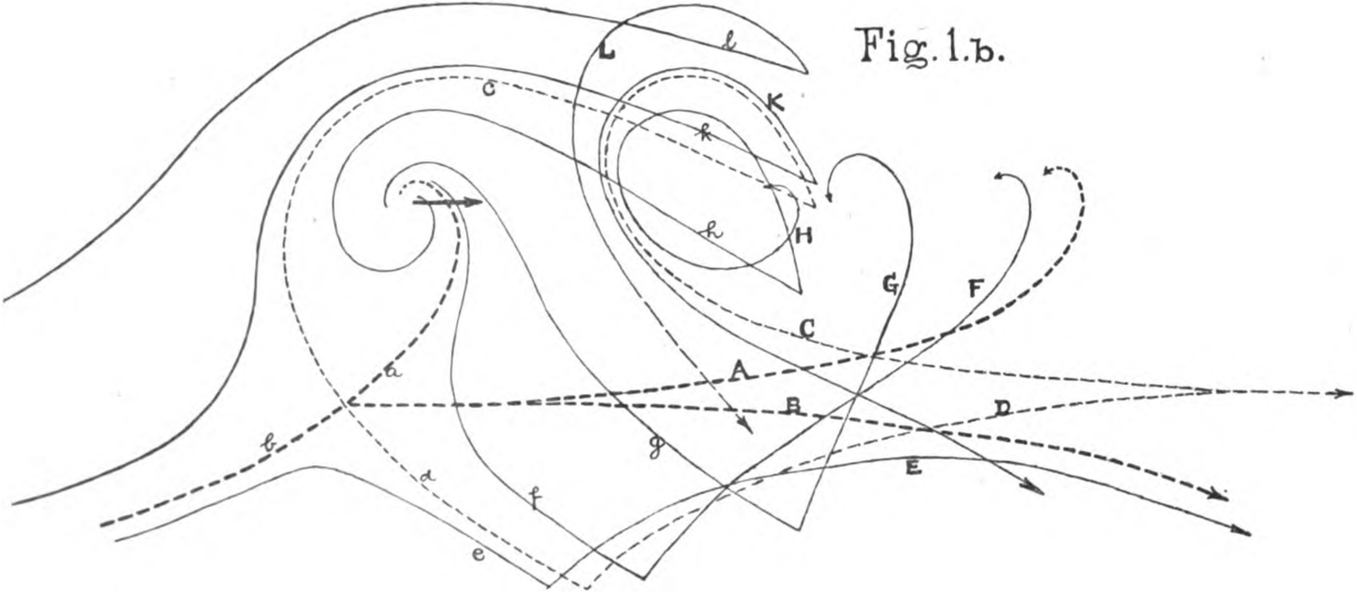
[1] "The Life History of Surface Air Currents." M.O. 174, 1906, plates III. and IV. *See also* Shaw, W. N., "Forecasting Weather," 1st ed., pp. 199-201.

Fig. 1.b.



Some trajectories over the earth's surface A, B, C, etc., transformed from lines of flow *a*, *b*, *c*, etc., which refer to a moving centre.

becomes smaller than the translational velocity of the centre when the distance from the centre increases. 2. The translational velocity is smaller than the wind velocity of the inner part. If we want to consider irregular distributions of wind speeds as well as the values of J and α, representing the surface conditions and the orientation, we can make a graphical construction, and we always get a line of discontinuity, which is explained below.

By Fig. 1 we see that the lines of flow, which were formerly a distance apart, come into contact along the thick dotted line ABC. Therefore, if a temperature gradient exist in the direction perpendicular to the motion of the cyclone, a discontinuity of temperature must occur along this line, which makes the squall line. If this view be true, the squall line must vanish when the cyclone comes to a region without temperature gradient, and be formed again when it comes to a region with a gradient. The phenomenon of a strong line squall, therefore, seems to occur after the entry of a cyclone into a region where there is a large gradient of temperature.

The equation of the squall line is obtained as follows. The squall line passes the point B, where no current exists relative to the origin. This point is expressed by $\theta = 270° - \alpha$, $r = \kappa R$. Substituting these values for θ and α in the equation (15), we can find the value of the constant of that equation for the squall line. The constant of the equation (13) is to be determined so as to be continuous with the above equation at $r = R$.

We have considered Fig. 1 to correspond to the flow near the earth's surface. Now, let the values of α and J, and consequently of κ, change with height as follows:[1]

Height in m.	α	κ
0	20°	3
200	16°	4·5
400	12°	5·1
600	8°	5·3
800	4°	5·3
1000	0°	5·3

The positions of the discontinuity lines at different heights calculated from the above values are shown in Fig. 2.

The thick full line is the projection of the locus of the point B. The thin full lines are the lines of flow at 200 m., showing how these currents pass over the discontinuity line near the surface.

For convenience sake, let us assume the direction of progress of the cyclone to be to the east. Then, if the temperature is higher towards the south, the south-east side of the discontinuity line is warmer. Hence, it has the same sense as the squall line in the northern hemisphere. In that case the state of Fig. 2 is unstable, and the cold air which has crossed the discontinuity line on the surface must fall down to the front of that line. If we take into consideration the line discontinuity on the surface only, it will advance with the same velocity as the centre. But, owing to the falling down current, the squall line must progress faster than the centre. This seems to be a more satisfactory mechanism than that of Bjerknes's. The feature of the boundary surface of the cold and warm air above this line may be quite different from that of W. Schmidt's experiment,[1] which shows the manner of propagation of denser air by gravity only.

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[1] See Dobson, G. M. B., *Q.J.R. Meteor. Soc.*, **40**, 1914, p. 123.

In Fig. 1 the thin dotted line EBF, which is expressed by the same equation as the line ABC, is the boundary of two kinds of flows: one, coming inside the boundary, reaches the central region and climbs up; the other, running outside of it, flows away to the rear of the cyclone (speaking relatively). Therefore this line may be called the *boundary of centripetal current.*

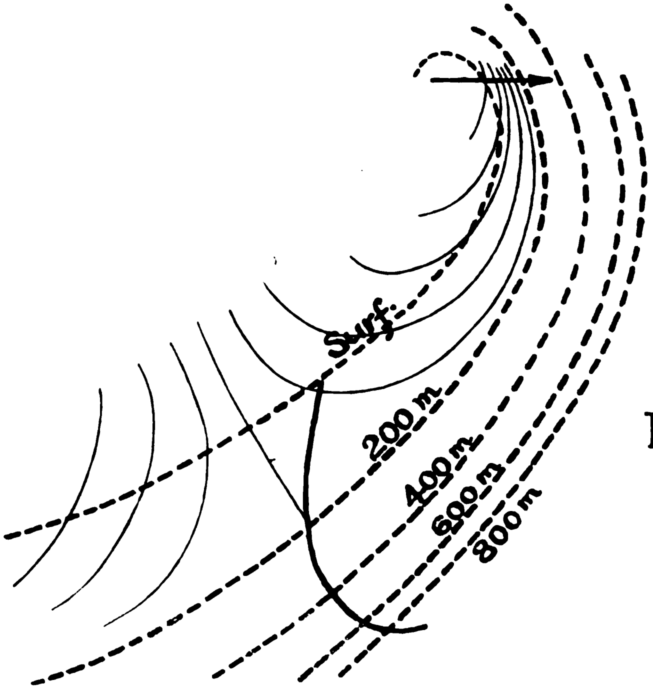

Fig. 2.

Positions of lines of discontinuity at different heights.

It is necessary to observe the features of flow prolonging farther both the line of discontinuity and the boundary of centripetal current. To do this, assume the path of the centre of the cyclone to be a straight line, and take six points on this line, distant 10 R, 25 R, and 50 R from the centre, in both directions, where R is the radius of the principal part. From the preceding equations find the lateral distances of the lines of discontinuity and the boundaries of the centripetal current from these points. Then we get the following figures :

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[1] *Met. Zs.*, **28**, 1911, p. 357.

[TABLES.

DISTANCES OF THE LINES OF DISCONTINUITY FROM THE AXIS.
(Unit: R.)

Height in m.	at 10 R.	25 R.	50 R.
0	5·94	8·03	9·77
200	8·27	11·05	13·65
400	9·29	12·56	15·53
600	9·80	13·27	16·42

DISTANCES OF THE BOUNDARIES OF THE CENTRIPETAL CURRENTS FROM THE AXIS.

Height in m.		at 10 R.	25 R.	50 R.
0	North	1·62	4·20	6·30
	South	8·15	10·59	12·56
200	North	2·13	6·13	9·09
	South	10·72	13·99	16·89
400	North	3·54	8·07	11·52
	South	11·47	15·03	18·24
600	North	5·38	10·00	13·54
	South	11·30	15·00	18·30

LATERAL DISTANCES OF NORTH AND SOUTH BOUNDARIES.

Height in m.	at 10 R.	25 R.	50 R.
0	6·53	6·39	6·26
200	8·59	7·86	7·80
400	7·93	6·96	6·72
600	5·92	5·00	4·76

When these lateral distances are corrected for the inclination, the real widths are as follows.

THE WIDTHS OF THE CENTRIPETAL CURRENTS.

Height in m.	at 10 R.	25 R.	50 R.
0	6·3	6·3	6·3
200	8·0	7·7	7·7
400	7·3	6·8	6·6
600	5·3	4·8	4·6

The full positions of these lines are shown in Fig. 3. Of course the lines of discontinuity do not stay in these positions. But the diagram shows that the distances between these lines at different heights still increase even at 50 R, so that the current of the higher level crosses the lower discontinuity line and the falling down continues.

We can see by this diagram that the air flowing into the cyclone does not come from all directions, but only the air lying between these boundary lines flows into the central part of the cyclone and climbs up. The width of the belt of the inflowing air is a maximum at about 150 m., and above that height it diminishes with height, becoming zero at 1000 m.

Since we know the width of this belt we can calculate the difference of the temperatures on both sides of the squall line, if the gradient of temperature be known.

From what we observed above it can be said that a moving cyclone takes off a belt of air and brings the air on both sides of it into contact, so that when there exists a temperature gradient in its field it makes the energy of that gradient available on the squall line.

§ 2. The Formation of Steering Lines.

For the formation of steering lines the writer has not sufficient data to determine the actual causes. But he offers the following four theories which seem most probable.

1. We can imagine that, when there is inward flow accompanied by climbing in a field with a temperature gradient, the steering line can develop from a small temperature discontinuity caused by the earth's surface or otherwise. The writer has observed in his former paper[1] a secondary cyclone, which was induced on the squall line of the main cyclone and had a new steering line separately from that of the main cyclone.

2. The discontinuity line of temperature, which becomes the steering line, may have been created by the preceding cyclone. As was explained in § 1, a cyclone leaves a discontinuity line of temperature in its wake. When the cyclone passes away the falling down over the squall line ceases, and the discontinuity remains, increasing the inclination of the boundary

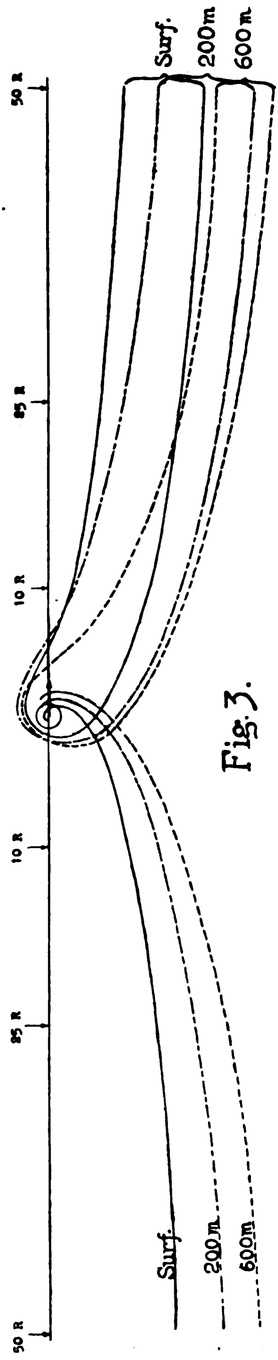

Fig. 3.

Lines of discontinuity and boundaries of the centripetal current prolonged to 50 times the radius of the principal part of the cyclone.

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[1] *Loc. cit.*

surface. If a cyclone catch this line once it will keep it as its steering line. If this theory be correct, an isolated cyclone, or the first cyclone of a family, ought not to have a steering line, while late members of a family may have one.

3. It is a well-known fact that the tropical cyclones first occur in the tropical zone, and proceed to the north-west. When they enter the temperate zone, they turn their course to the north-east. Now let us consider a cyclone still advancing toward the north-west. Then it will be seen that the discontinuity line must be produced on the right-hand rear quadrant, extending towards north-east. If the temperature be higher to the south, what may be called the warm sector surrounds the three sides, and the north quadrant only is cold. The warm current of the higher layers crossing the discontinuity line of the surface spreads over the cold air on the cold side of the line. This construction is stable, and the same as that of the steering line. The cyclone changes its course when it enters the temperate zone, where the latitudinal temperature gradient is larger and the deviating force caused by the rotation of the earth greater, consequently the discontinuity can develop strongly. This discontinuity line of temperature may become the steering line after the cyclone changes its course. This origin is very probable, but the writer has no actual data about it. Only in the southern part of the United States of America when a cyclone is advancing to the north-west, the isothermal lines, in most cases, curve sharply from the north towards the centre. This fact shows that a narrow cold sector is formed.

4. Anticyclones also, when they travel through the general atmosphere, leave discontinuity lines of temperature (see § 4). In the former paper the writer pointed out that the steering line of a cyclone reached the centre of a moving high, and the high moved with the advance of the steering line. This origin is also probable.

The writer believes that the steering line is not essential for a cyclone, but when a cyclone catches a line of temperature discontinuity produced from any cause, the cyclone will keep it as the steering line. He intends to discuss this point later, when he has succeeded in collecting sufficient data.

§ 3. Cyclone with Polar Fronts.

The feature of flows in a cyclone without the steering line has been explained in § 1. When a steering line, as the Bjerknes's diagram shows, comes in from the south-east, it will be modified probably as Fig. 4.

The thick full lines are the polar fronts, and the thin full lines are the lines of flow on the surface of the earth. The dotted lines are the original positions of modified lines, the same as in Fig. 1. Since the cold currents of higher layers cross the discontinuity line on the surface, and constantly fall down to the front of it, the squall line advances far before the line of discontinuity. The warm currents, which are impeded by this advance, must climb up.

The stream-lines between the squall line and the discontinuity line on the surface are drawn in the directions of flow at the higher levels; to the part near the discontinuity line, giving the direction of flow at a small height; and to the part nearer the squall line, the direction of it at the still higher level. (The flow in this part is not stationary, so that these stream-lines are not lines of flow.)

The fact that the steering line comes to the position shown in the diagram, not curving towards the north with the lines of flow, is very probable, because the cold current near the steering line is covered by the warm current, and consequently, the propagation of the velocity of the higher layer—warm current—to the lower layer—cold current—must be smaller than in the continuous case. Moreover, the velocity of this warm current is also smaller than the velocity proper to the height, because it is climbing from the lower level.

The lines of flow on the cold side of the steering line must be strongly deviated to the south. The advance of the steering line towards the cold side must be due to this insufficiency of lines of flow on the cold side.

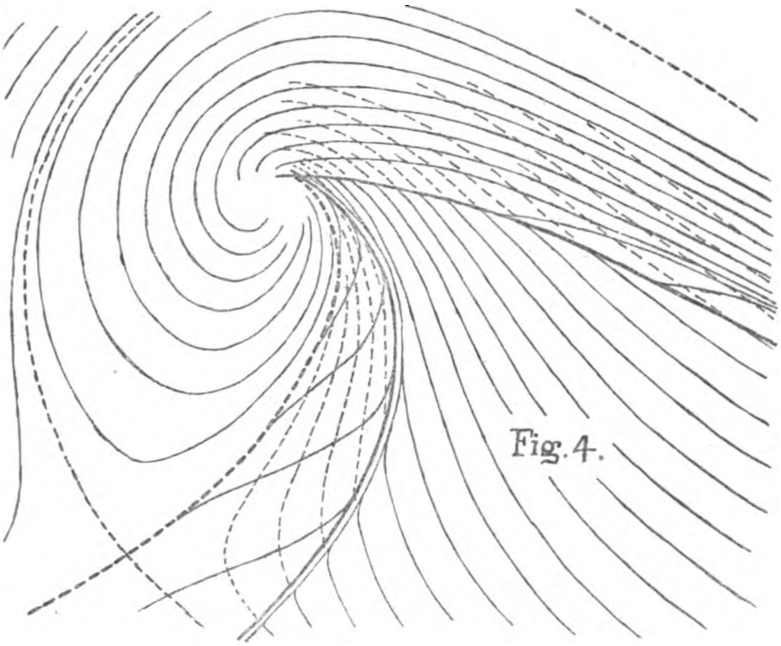

Fig. 4.

Lines of flow modified by polar fronts, which are represented by thick full lines.

When Fig. 4 is transformed into a synoptic chart of stream-lines, fixed relative to the earth, we get the very same diagram as Bjerknes's.

§ 4. Anticyclones.

The pressure distribution in an anticyclone is generally more irregular than that of a cyclone. Therefore, it may be unreasonable to use the same treatment as in § 1. But if we assume that the isobars are nearly concentric circles, and the wind dwindles away with the distance from the centre outside a certain area, we obtain the same kind of diagram as Fig. 1, excepting the central part, where there is calm. But in Fig. 1 the sense of the motion of the centre and the lines of flow must be reversed. Then the line ABC becomes the boundary of two flows which separate afterwards, and the line EBF becomes the discontinuity line. The descending air in an anticyclone is generally warmer than the surrounding air, because it is adiabatically compressed, while the temperature lapse-rate of the surrounding region is always smaller than the adiabatic. Only when clouds are carried into the region of descending air, and evaporated in it, the temperature may be lower than that of the surrounding air. Therefore, an anticyclone leaves two lines of temperature discontinuity in its wake, though the discontinuity may generally be very small.

In conclusion, the writer wishes to express his thanks to Sir Napier Shaw for valuable assistance given during the preparation of the paper.

[In the absence of the author, this paper was read by Captain D. Brunt, who kindly corrected the final proofs. *Editing Committee.*]

DISCUSSION.

Dr. G. C. SIMPSON said he thought, when reading the paper, that it was the most fascinating one that had been before the Society for a long time. There had been many attempts to establish a theory of the cyclone, but one still felt that the question was very much open. Personally, he had always objected to one feature of Bjerknes's theory. His cyclone is a cyclone which depends on chimney action ; it is supported by its own energy, which is obtained from the discontinuities which are found on the surface. Bjerknes seems to imply that the primary thing in a cyclone is a discontinuity and that cyclones follow, having once given the polar front. This paper has definitely established that given a temperature gradient from south to north and a moving whirl, then you get immediately the main discontinuity lines which we know from our observations exist in cyclones. He had read the paper with great pleasure until he got to § 2 ; from there he felt we were coming back again to the Bjerknes theory. If he were not mistaken, after § 2 mathematics have been left entirely behind and everything becomes what would be expected from preconceived ideas. After describing the line of discontinuity in the wake of the cyclone, the author goes on : "If a cyclone catch this line once it will keep it as its steering line." Perhaps Capt. Brunt could tell us if this is a mathematical deduction ? Why should it catch that discontinuity ? Why should it use it as a steering line ? It does not appear to follow from the previous part of the paper.

Mr. N. L. SILVESTER said that in § 4 the author assumes that the wind dwindles away with the distance from the centre outside a certain area. Is he justified in making this assumption, since observations indicate that in the normal anticyclone wind velocity generally increases with distance from the centre ?

Mr. M. A. GIBLETT said he thought this paper one of very great interest. The author had produced something so remarkably resembling a "squall line" merely by the passage of a rotating system across a field in which there was a horizontal temperature gradient, that its properties deserve very close attention. It was necessary in considering the results to be quite clear that the treatment was purely kinematical and not dynamical. The motion was completely defined in the initial assumptions of a travelling circular system with a given wind distribution, and was merely exhibited in another and more instructive way in the subsequent diagrams. The motion shown in the diagrams was not deduced as the result of the operation of natural forces. The discontinuity produced (ABC in Fig. 1) was a very shallow one, and depended solely on the incurvature of the wind in the lower layers. The contrast of temperature on the two sides no longer existed at the moderate height at which the wind attains the gradient value. The absence of a discontinuity at so low a level would not be acceptable to those who consider there is sufficient observational evidence that the discontinuities in a cyclone extend, in general, considerably higher than this. The layers dealt with were layers of active mixing; in fact, the assumed variation of wind with height depended on it, and this raised the question as to whether the mixing of the lowest air-streams with those above from different sources (see Fig. 3) would appreciably modify the results. He shared Dr. Simpson's difficulties about the second part of the paper. He did not intend these remarks to detract from the value of the paper, which he thought very great.

Captain D. **Brunt** thought Dr. Simpson's question could be settled by reference to Fig. 1. Along the line ABC air originating along BE is brought into juxtaposition with air originating along BF. If originally there is a horizontal gradient of temperature at right angles to the direction of motion of the cyclone—as happens when a depression moves eastward, and there is a south-north gradient of temperature—then air on opposite sides of ABC will have different temperatures, so that this is a line of discontinuity of temperature. The discontinuity of temperature remains along BA after the depression has passed away, and if another depression follows the first, it retains this discontinuity. But it is not necessary to assume that the line of discontinuity in front is a steering line, as it is not at all clear that it will have any steering properties. He thought the point which Mr. Kobayasi makes is correct, that an isolated cyclone should not have a line of discontinuity from the centre forwards, whereas the second and third of a "family" may have two lines of discontinuity. That point is independent of whether the line functions as a steering line or not. With regard to Mr. Giblett's question, which referred to Fig. 3, Mr. Brunt was not prepared to discuss this without notice. In practice the so-called surface of discontinuity might be as thick as 1000-2000 feet. Observations of wind have made that clear. In an observation on March 12th this was the case when, with a strong Northerly current above a Southerly wind, it took 1000 feet for the Southerly current to die away and another 1000 feet for the Northerly current to grow. It is not at all obvious how turbulence and instability will develop in detail when a layer of transition of such a thickness is substituted for the theoretical thin separating surface postulated in Figs. 2 and 3.

NOTES ON THE FLUCTUATIONS OF MEAN SEA-LEVEL IN RELATION TO CHANGE OF ATMOSPHERIC PRESSURE, FROM OBSERVATIONS AT LIVERPOOL, AUGUST AND SEPTEMBER 1920.

By Captain E. C. SHANKLAND, R.N.R., F.R.Met.Soc.

[Received September 26, 1922—Read April 18, 1923.]

During last century and intermittently during the present one, observers have endeavoured to compute the ratio of change of mean sea-level to change in barometric pressure, and have assigned to it varying values. A significant feature lies in a tendency to increase the value of the factor as investigation has progressed.

With a view of testing the maximum which has come under the notice of the writer—(*i.e.*) that the variation of sea-level is approximately 20 times the magnitude of barometric variation—the tabulated data from actual observations were prepared. It may be appropriate to remind the reader that the density ratio of sea water to mercury is as 1 is to 13·25, and consequently is not in accord with the maximum above mentioned.

The selection of locality is a difficulty not easily surmounted, owing to the more precise predictions in our nautical tide-tables being allotted to the seaports and waterways of navigable importance. These localities are invariably unsuitable for free tidal movement, and, as the chart which accompanies this paper illustrates, those in the British Isles are remote from the deep water or 100-fathom contour.

The tabulated results do not throw an unfavourable light on the estimate of 1/20, and although the observations are limited and, consequently, an approximation, the approximation is not so much due to quantitative error as it is to the complex measure of physical factors surrounding it. The statement that the mean sea-level rises and falls as the mercury falls and rises, is generally accepted as axiomatic. We are confronted, however, in estuaries with quite a normal range, with the fact that for a considerable period of the tide the water-level is below that of mean sea-level, and so much so in some localities that rocks and sand-banks protrude, impressing on us that the tidal level then is actually a hiatus to a plane of the oceanic level produced to meet the coast-line. At such a tidal period the local conditions are a negation of the physical operations we desire to co-relate with barometric change. But at periods of tide when the water-level rises above that of mean sea-level no such negation occurs, for the local level is then, by being superposed on mean sea-level, not unfavourable for examination.

That the tidal rise and fall in the open ocean beyond the 100-fathom line is estimated at 2 ft. or 3 ft., whereas in estuaries and harbours on the coast it reaches 30 ft. and 40 ft., is due in the latter instance to hydraulic agency, in which the gradient of the submarine land and the configuration of the locality are the leading factors.

The most remarkable example of the configuration anomaly is probably found in the Bay of Fundy, where the tides within the pocket of land formed by Nova Scotia and New Brunswick rise to 50 ft. above the low-water level, while on the seaboard a few miles across the isthmus, where the tidal wave has free play, the range does not exceed one-quarter of that observed in the bay. Although this great difference of range in configurated coastal waters, as compared with oceanic water, does not affect the ascertainment of a mean sea-level at any place, the rapid rise and fall in the former case is more likely to produce unexplained oscillations and tideograph discordances.

The main factors operating to produce these discordances are well known to tidal computers, and are too complex to be adequately covered in this paper. It should, however, be borne in mind that errors in phase and amplitude of predictions computed from observations obtained in tidal basins so configurated are not infrequent. We are therefore compelled to recognize two primary deficiencies in tidal deductions:

(1) That the range and fluctuation of mean sea-level in the deep-ocean basins and in configurated harbours are interdependent, and their respective records are sympathetic.

(2) That when endeavouring to fix the limits of tidal areas affected by oscillations of barometric pressure we cannot dispose of the unknown contiguous effects that are elsewhere in operation.

In the latter case, as far as the present observations are concerned, the difficulty has been met by utilizing tidal sets which covered periods of an extensive anti-cyclonic type, light winds and smooth seas prevailing. The selected observations are confined to tide level at high water, during which the atmospheric pressure was remarkably constant. The three main types of tide are dealt with, namely, the synodic, the anomalistic, and declinational. Fig. 1 illustrates the position of the 100-fathom line, beyond which the estimated range of mean sea-level is approximately 3 ft. Rockall Island, which stands like a tide-pole in the Atlantic, some 280 miles west of St. Kilda, is possessed of a tidal range which has been estimated at 6 ft., presumably at lunar full and change. Insufficiency of observations is admitted; add to this a constant Atlantic swell further to detract from the value of the figure.

The foregoing remarks lead us to the explanation of the methods adopted in the tabulated results which follow, groups 1, 2, 3. Predicted heights and times of high water, as given in the Admiralty tide-tables, are placed side by side with those recorded as they have occurred at the place of observation. The actual difference in phase at each tide is noted by the letter (*r*) in the case of retardation in phase, and (*a*) for acceleration. Similarly the amplitude is noted with the minus sign (–) to indicate a tide level which is below the predicted level, and the plus sign (+) where the predicted level is exceeded. The synchronous barometric pressure at each observation follows in the next column, preceding its correction for altitude above mean sea-level, and the corrected value then compared with the mean annual air pressure of the place, obtained from the Meteorological Office Report, also raised correspondingly.

From this Report is also obtained the mean temperature of the month as the temperature standard. It should therefore follow that the actual mean depression in inches of a tide level occurring at a time when the barometric pressure was above a recognized normal should be closely in agreement with an estimated mean depression attributable to barometric fluctuation if the formula is satisfactory.

Briefly to summarise these results, we have in

Group 1.—Actual mean depression for 9 tides, 4·55 ins.; computed barometric depression or M.T.E. all tides, 5·83 ins.; computed differing, 1·28 in. only, and in excess.

Group 2.—Actual mean depression for 19 tides, 7·47 ins.; computed barometric depression for 19 tides or M.T.E., 6·32 ins.; computed differing, 1·15 in. only, and a deficiency.

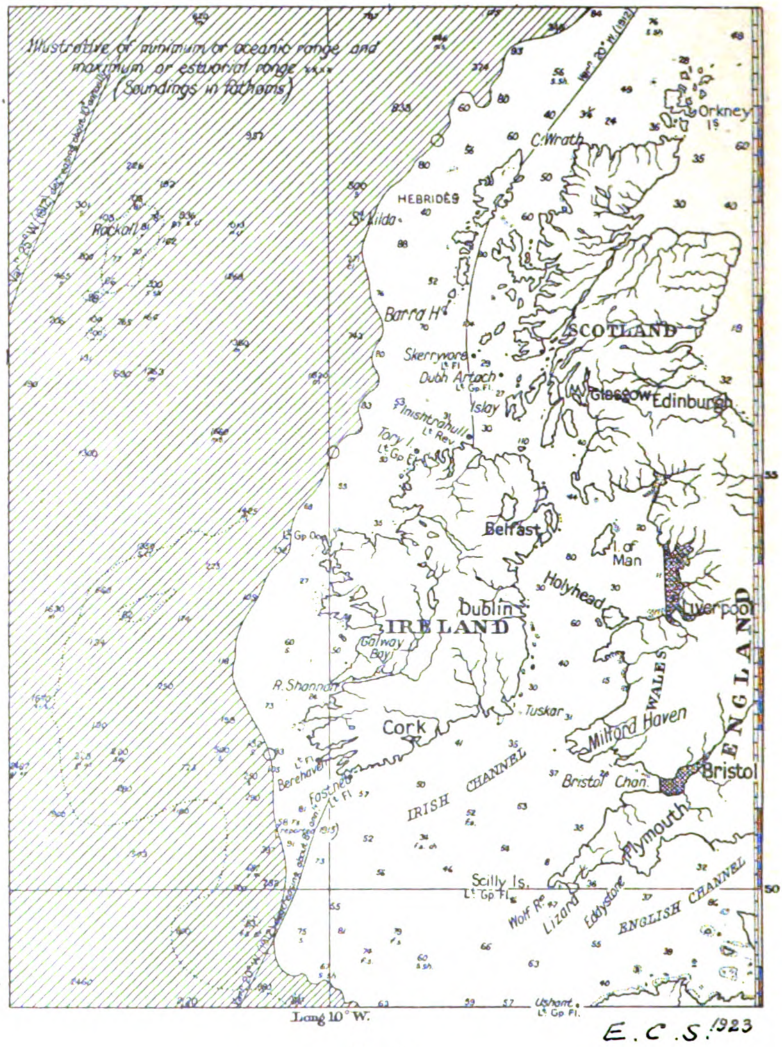

FIG. 1.

Group 3.—Actual mean depression for 13 tides, 7·08 ins.; computed barometric depression or M.T.E., 4·96 ins.; computed differing, 2·12 ins., and a deficiency.

M.T.E. represents meteorological tidal equation or a correction

TABLE I.—1st Group.

1920. August G.M.T.	High water (predicted).				High water (recorded).				Actual difference.			Synchronous barometric pressure reduced to M.S.L.	Correction of each tide for rise above M.S.L.			True synchronous barometric pressure.	Mean annual air pressure at place (Meteorological Office values) 29·940 ins., 1014 mb.		
	Time.		Height.		Time.		Height.		Phase.	Amplitude.			Tidal rise.		Bar. corr.	A.	B.	A-B.	20 (A-B).
	H.	M.	Ft.	Ins.	H.	M.	Ft.	Ins.	Min.	Ft.	Ins.	Ins.	Ft.	Ins.	In.	Ins.	Ins.	In.	Ins.
10th a.m.	7	08	23	6	7	04	24	0	4 a	+0	6	30·13	9	4	0·009	30·12	29·93	0·19	−3·8
p.m.	7	46	24	6	7	48	24	3	2 r	−0	3	30·20	9	7	0·010	30·19	29·93	0·26	−5·2
11th a.m.	8	26	24	8	8	28	24	11	2 r	+0	3	30·26	10	3	0·010	30·25	29·93	0·32	−6·4
p.m.	8	57	26	2	8	58	25	10	1 r	−0	4	30·32	11	2	0·011	30·31	29·93	0·38	−7·6
12th a.m.	9	32	26	4	9	33	26	4	1 r	0	0	30·31	11	8	0·012	30·30	29·93	0·37	−7·4
p.m.	9	54	28	2	9	53	27	6	1 a	−0	8	30·26	12	10	0·013	30·25	29·93	0·32	−6·4
13th a.m.	10	25	27	11	10	29	27	9	4 r	−0	2	30·24	13	1	0·014	30·23	29·93	0·30	−6·0
p.m.	10	43	29	7	10	45	29	0	2 r	−0	7	30·23	14	4	0·015	30·22	29·93	0·29	−5·8
14th a.m.	11	13	28	11	11	15	28	10	2 r	−0	1	30·24	14	2	0·015	30·23	29·93	0·30	−6·0
p.m.	11	28	30	6	11	35	29	11	7 r	−0	7	30·25	15	3	0·016	30·23	29·92	0·31	−6·2
15th a.m.	...		...		...		...		...	...		...	...		...	...	...	...	...
p.m.	11	59	29	4	12	04	29	4	5 r	0	0	30·23	14	8	0·015	30·22	29·93	0·29	−5·8
16th a.m.	0	13	30	10	0	18	30	3	5 r	−0	7	30·20	15	7	0·017	30·18	29·92	0·26	−5·2
p.m.	12	43	29	5	12	43	29	3	0	−0	2	30·14	14	7	0·015	30·13	29·93	0·20	−4·0

Notes.—The number of tides examined = 13.

Number of these recording a depressed tidal level = 9 as compared with the Admiralty predictions. } Retarded in phase 7. Advanced in phase 1. In agreement in phase 1.

Number of these recording an elevated tidal level = 2 as compared with the Admiralty predictions. } Retarded in phase 1. Advanced in phase 1.

Number of these in agreement with predicted levels = 2. } Retarded in phase 2.

Barometric pressure was above the average pressure at the place during entire series.

The actual mean depression for the 9 tides = 4·55 ins. {
The computed mean depression by formula—
rise
1 bar. inch : 20" : : A ~ B : M.T.E.
fall
which for 13 tides = 5·83 ins.
" 9 " = 5·82 ins.

The mean retardation of all depressed-retarded tides (8) = 3·0 mins.

TABLE II.—2ND GROUP.

1920. August G.M.T.	High Water (predicted).				High Water (recorded).				Actual difference.			Synchronous barometric pressure reduced to M.S.L.	Correction to each tide for rise above M.S.L.			True synchronous barometric pressure.	Mean annual air pressure at place (Meteorological Office values) 29·940 ins., 1014 mb.		
	Time.		Height.		Time.		Height.		Phase.	Amplitude.			Tidal rise.		Bar. corr.	A.	B.	A-B.	20 (A-B).
	H.	M.	Ft.	Ins.	H.	M.	Ft.	Ins.	Min.	Ft.	Ins.	Ins.	Ft.	Ins.	In.	Ins.	Ins.	In.	Ins.
22nd a.m.	4	39	22	9	4	29	22	4	10 a	−0	5	30·06	7	8	0·006	30·05	29·93	0·109	− 2·18
p.m.	5	12	22	3	5	05	21	11	7 a	−0	4	30·10	7	3	0·006	30·09	29·93	0·149	− 2·98
23rd a.m.	5	49	21	8	5	45	21	4	4 a	−0	4	30·07	6	8	0·005	30·06	29·93	0·118	− 2·36
p.m.	6	24	21	11	6	26	21	3	2 r	−0	8	30·11	6	7	0·005	30·10	29·93	0·158	− 3·16
24th a.m.	7	08	21	6	7	14	20	10	6 r	−0	8	30·12	6	2	0·005	30·11	29·93	0·168	− 2·36
p.m.	7	43	22	3	7	45	22	0	2 r	−0	3	30·13	7	4	0·006	30·12	29·93	0·179	− 3·58
25th a.m.	8	23	22	3	8	23	21	10	0	−0	5	30·14	7	2	0·006	30·13	29·93	0·189	− 3·78
p.m.	8	49	23	5	8	54	23	4	5 r	−0	1	30·22	8	8	0·007	30·21	29·93	0·270	− 5·40
26th a.m.	9	23	23	6	9	19	22	11	4 a	−0	7	30·34	8	3	0·007	30·33	29·93	0·390	− 7·80
p.m.	9	40	24	11	9	40	24	9	0	−0	2	30·36	10	1	0·010	30·35	29·93	0·413	− 8·26
27th a.m.	10	09	24	11	10	02	24	3	7 a	−0	8	30·40	9	7	0·010	30·39	29·93	0·453	− 9·06
p.m.	10	20	26	6	10	16	26	0	4 a	−0	6	30·43	11	4	0·012	30·42	29·93	0·485	− 9·70
28th a.m.	10	46	26	2	10	42	25	3	4 a	−0	11	30·46	10	7	0·010	30·45	29·93	0·513	− 10·26
p.m.	10	55	27	7	10	52	26	11	3 a	−0	8	30·45	12	3	0·015	30·44	29·93	0·508	− 10·16
29th a.m.	11	19	27	2	11	15	26	0	4 a	−1	2	30·47	11	4	0·012	30·46	29·93	0·525	− 10·50
p.m.	11	27	28	6	11	29	27	9	2 r	−0	9	30·44	13	1	0·016	30·42	29·92	0·499	− 9·98
30th a.m.	11	51	27	10	11	48	26	11	3 a	−0	11	30·31	12	3	0·016	30·29	29·92	0·359	− 7·18
p.m.	...		...		...		...		...	...		...	...		...	...	...	...	...
31st a.m.	0	0	29	1	0	0	28	3	0	−0	10	30·26	13	7	0·017	30·24	29·92	0·310	− 6·20
p.m.	12	24	28	11	12	16	27	5	8 a	−1	6	30·21	12	9	0·016	30·19	29·92	0·259	− 5·18

Notes.—The number of tides examined = 19.

Number of these recording a depressed tidal level as compared with the Admiralty predictions = 19. } Retarded in phase 5. Advanced in phase 11. In agreement in phase 3.

Number of these recording an elevated tidal level as compared with Admiralty predictions. } Nil.

The actual mean depression for 19 tides = 7·47 ins. { The computed mean depression by formula (M.T.E.) for 19 tides = 6·32 ins.

Mean retardation for all depressed-retarded tides (5) = 3·4 min.

Barometric pressure was above the average pressure of the place during entire series.

Mean rainfall for Groups I. and II., Meteorological Office values. } 59 per cent of normal.

Mean temperature. } 56°·5 F.

Temperature standard for computing A ~ B. } 54° F.

During Group I. and Group II. the range of barometric pressure and temperature was slight.

TABLE III.—3rd Group.

1920. September G.M.T.	High water (predicted).		High water (recorded).		Actual difference.		Synchronous barometric pressure reduced to M.S.L.	Correction to each tide for rise above M.S.L.		True synchronous barometric pressure.	Mean annual air pressure at place (Meteorological Office values) 29·940 ins. 1014 mb.		
	Time.	Height.	Time.	Height.	Phase.	Amplitude.		Tidal rise.	Bar. corr.	A.	B.	A-B.	20 (A-B).
	H. M.	Ft. Ins.	H. M.	Ft. Ins.	Min.	Ft. Ins.	Ins.	Ft. Ins.	In.	Ins.	Ins.	In.	Ins.
22nd a.m. .	6 20	21 2	6 30	19 9	10 r	− 1 5	30·32	5 1	0·005	30·31	29·93	0·368	− 7·36
p.m. .	6 55	21 11	7 00	20 11	5 r	− 1 0	30·20	6 3	0·005	30·19	29·93	0·248	− 4·96
23rd a.m. .	7 44	21 10	7 50	21 2	6 r	− 0 8	30·31	6 6	0·006	30·30	29·93	0·359	− 7·18
p.m. .	8 12	23 0	8 23	23 0	11 r	0 0	30·30	8 4	0·007	30·29	29·93	0·350	− 7·00
24th a.m. .	8 51	23 3	8 56	22 9	5 r	− 0 6	30·29	8 1	0·007	30·28	29·93	0·340	− 6·80
p.m. .	9 09	24 8	9 09	24 9	0	+ 0 1	30·18	10 1	0·010	30·17	29·93	0·233	− 4·66
25th a.m. .	9 39	24 11	9 32	24 2	7 a	− 0 9	30·12	9 6	0·010	30·11	29·93	0·193	− 3·86
p.m. .	9 50	26 5	9 44	26 3	6 a	− 0 2	30·16	11 7	0·012	30·15	29·93	0·215	− 4·30
26th a.m. .	10 16	26 6	10 07	26 2	9 a	− 0 4	30·16	11 6	0·012	30·15	29·93	0·215	− 4·30
p.m. .	10 25	27 11	10 20	27 9	5 a	− 0 2	30·13	13 1	0·016	30·11	29·92	0·179	− 3·58
27th a.m. .	10 49	27 7	10 47	27 3	2 a	− 0 4	30·14	12 7	0·016	30·12	29·92	0·199	− 3·98
p.m. .	11 00	29 0	10 51	28 7	9 a	− 0 5	30·19	13 11	0·017	30·17	29·92	0·250	− 5·00
28th a.m. .	11 22	28 8	11 25	27 9	3 r	− 0 11	30·22	13 1	0·017	30·20	29·92	0·280	− 5·60
p.m. .	11 34	29 8	11 34	29 5	0	− 0 3	30·16	14 9	0·017	30·14	29·92	0·219	− 4·38
29th a.m. .	11 56	29 2	11 49	28 5	7 a	− 0 9	30·10	13 9	0·017	30·08	29·92	0·160	− 3·20

Notes.—The number of tides examined = 15.

Number of these recording a depressed tidal level as compared with Admiralty predictions = 13. } Retarded in phase 5. Advanced in phase 7. In agreement in phase 1.

Number of these recording an elevated tidal level = 1. } In agreement in phase.

Number in agreement with predicted level = 1. } Retarded in phase.

The actual mean depression for the 13 tides = 7·08 ins. { The computed mean depression by formula (M.T.E.) for 15 tides = 5·08 ins. „ 13 „ = 4·96 „

Mean retardation for all depressed-retarded tides (5) = 5·8 min.

Barometric pressure was above the average pressure of the place during entire series.

Mean rainfall, September, Meteorological Office values. } 95 per cent of normal.

Mean temperature. } 57° F.

Temperature used for computing A ~ B. } 54° F.

applicable to tidal predictions from change in barometric pressure, the ratio used in this paper being that assumed in the *Admiralty Manual of Navigation*, 1914, p. 138, Article 246, viz. 1 inch variation of M.S.L. to $\frac{1}{20}$ inch of mercury; the mean isobar representing the barometric datum line and the tidal predictions calculated by harmonic analysis, the M.S.L. for elevation of tidal levels, being that of the ordnance datum.

DISCUSSION.

Mr. C. S. **Durst** thought the most striking thing about this paper was that the variation of sea-level is approximately 20 times the barometric variation, instead of 13·25, which is the ratio of the density of mercury to water. The author said that he had taken occasions on which there had been light wind. Mr. Durst had looked up the *Daily Weather Report* for the days on which the observations were made and found that the wind on two occasions was force 4, and on other occasions it was 3 and 2. He had put down the values of the wind against the discrepancies that were found, and then arranged them as the wind was East and West to see if there were any connection between the wind force and the difference in the height of the tide. The figures he got were as follows:—

	Wind from West.					Wind from East.		
Force	4	3	2	1	0	1	2	3
Mean discrepancy of observed from predicted tide height in inches.	+2	−5	−3	−6	−8	−7	−11	−11.

To him it appeared as though there was correlation between the direction and force of the wind and the discrepancy between the tide height and the predicted height. There was another point which was rather noticeable in the figures which he had taken out—that was the negative sign. If one looked at the mean pressure gradient at Liverpool for the year as given in *Weather of the British Coasts* one saw that the average wind is W, force 3, so that the mean sea-level is the sea-level when the wind is Westerly, force 3. When the wind is less than force 3, Westerly, you would expect the sea-level of the predicted height of the tide greater than the actual height. This is borne out by the negative sign. The Ordnance Survey had recently completed a network of levels over the British Isles and had connected up a tide-gauge in Cornwall with another in Scotland. The difference in mean sea-level between these two places was 0·8 of a foot. The Ordnance Survey had obtained a correlation between tide height and atmospheric pressure which accounted for 0·12 of a foot. The remaining 8 inches was attributed to the prevailing winds. Mr. Durst thought the author should have treated his observations for wind before he used them for obtaining differences of tide height due to pressure.

Captain E. C. **Shankland** said he had studied very carefully the introduction of wind force during the period of observation, and thought that he knew the observations referred to by Mr. Durst as winds of force 4. In general the difficulty which confronts one is, that if one starts correlating with the stronger winds at Liverpool the result is hopeless. This subject lent itself to a great deal of manipulation, and certainly to further examination and correlation with winds of lighter forces.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

March 21, 1923.

At the *Ordinary Meeting* the following candidates were balloted for and elected Fellows of the Society :—

TATUO KOBAYASI, Aeronautical Research Institute, Hukagawa, Tokyo, Japan ;

CYRIL WILLIAM SEYMOUR-HALL, Zanzibar, East Africa ;

GEORGE HUBERT WILKINS, M.C., Royal Societies Club, St. James's Street, S.W. 1 ; and

GLYNNE WILLIAMS, Hailey, Ipsden, Oxon.

April 18, 1923.

At the *Ordinary Meeting* the two following candidates were balloted for and elected Fellows of the Society :—

RICHARD LANCELOT BURROWS, M.I.H., Garland House, Upton, Langport, Somerset ; and

VICTOR DONALD GRANT, Instructor of Meteorology, T.S. *Indefatigable*, New Ferry, Birkenhead.

CORRESPONDENCE AND NOTES.

L. S. Korczynski on the Climate of Poland.

A "Treatise on Polish Balneology," by Professor L. S. Korczynski, has been communicated to the Society by Dr. R. Fortescue Fox. A summary of the sections dealing with spas and bathing-places has already been published in the *Archives of Medical Hydrology*, January 1923 ; the section on climate, which contains some useful tables, is summarised below.

The climate may be described as "temperate continental" ; it is influenced in the south-west by the Carpathians, and in the north by the proximity to the Baltic. Dealing first with the Polish Carpathian belt, we find a comparatively mild climate in the west, becoming more severe in the central part and again improving in the south-east. The temperature, rainfall, and cloudiness of various stations in the mountain zone are shown in the first half of Table I. In general the mountain climate is bleak, owing to the slope of the ground being to the north-east, while the warm Southerly winds are cut off. The range of temperature from winter to summer increases eastward, as also does the range within each season. Cloudiness decreases eastward ; in the west, autumn is clearest and spring cloudiest ; in the east, summer and autumn are least cloudy. Rainfall is heaviest in the western Carpathians and decreases eastward, but the amount is too variable to lay down rules. Summer is the rainy season over the whole of this belt. The prevailing wind is Westerly, but its direction is much modified by local circumstances. Wind frequencies for Bielsko in the Carpathians and Pinsk in the plains are given in Table II. No statistics appear to be available for the short Polish coast. The temperature is naturally less extreme than in the interior, but the cloudiness is great, and rainy days are numerous.

The climate of the great area of lowlands is mild compared with that of central Russia, owing to the vast forests. The range increases towards the east,

TABLE I.—Temperature, Rainfall, and Cloudiness in Poland.

Station.	Latitude N.	Longitude E.	Height.	Mean Temperature.					Extreme.*		Rainfall.					Cloud Amount.
				Winter.	Spring.	Summer.	Autumn.	Year.	Max.	Min.	Winter.	Spring.	Summer.	Autumn.	Year.	
I. Carpathians.	° ′	° ′	feet.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	mm.	mm.	mm.	mm.	mm.	0-10.
Bielsko	49 49	19 3	1129	27·3	44·2	63·3	48·4	45·9	90	− 1	165	312	468	177	1122	6·4
Iwonicz	49 36	21 48	997	23·2	44·4	63·9	49·1	45·5	87	− 6	154	171	223	181	729	5·6
Bohorodczany	48 47	24 33	1145	23·2	44·4	64·2	47·1	44·1	86	− 17	37	66	117	162	382	6·1
Kosow	48 19	25 9	1312	25·0	47·3	67·8	50·4	47·8	93	− 19	108	109	231	180	628	4·0
Kuty	48 19	25 15	1112	25·9	49·6	71·2	53·1	49·8	94	− 11	...	...	...	...	...	...
Rabka	49 36	19 59	1598	24·6	43·7	61·9	46·8	44·2	78	− 11	63	214	448	129	854	6·8
Szczawnica	49 26	20 30	1588	22·3	43·2	61·5	47·5	43·9	85	− 17	144	224	367	113	848	6·3
Delatyn	48 58	24 38	1391	24·1	45·5	65·1	48·7	45·3	88	− 4	56	168	205	176	605	...
Zawoja	49 49	19 33	1739	25·7	43·5	62·1	47·5	45·0	83	− 15	175	275	502	148	1100	...
Zakopane	49 18	19 57	2746	22·3	38·8	56·5	43·2	40·1	81	− 5	108	252	517	250	1127	6·0
Krynica	49 25	20 57	1923	24·8	43·2	60·6	46·2	43·7	80	− 15	115	263	380	135	893	6·6
Turka	49 9	23 2	1926	20·3	41·9	61·7	46·2	42·3	85	− 17	85	189	316	188	778	3·2
Krzyworownia	48 10	24 54	1788	21·0	42·4	62·1	45·7	42·4	85	− 18	57	117	227	132	533	5·8
II. Plains.																
Mlodzieszyn	52 17	20 12	312	28·6	49·3	63·3	44·8	46·4	95	− 9	90	81	122	126	419	4·2
Ostrowy	52 18	19 11	407	28·6	47·8	61·0	44·4	45·5.	87	− 7	75	107	127	130	439	6·0
Oryszow	52 6	20 20	394	28·6	48·7	62·2	44·8	45·7	94	− 10	61	116	180	133	490	6·0
Krasiniec	52 55	21 0	361	24·1	45·5	64·9	46·6	45·5	90	− 4	62	123	225	201	611	6·0
Pinsk	52 7	26 6	459	25·3	47·5	63·1	42·3	44·6	91	− 13	105	103	301	165	674	7·0
Rytwiany	50 30	21 10	623	26·6	48·7	62·4	45·5	45·9	83	− 6	34	102	199	111	446	6·0
Naleczow	51 20	22 8	689	26·1	47·5	61·9	44·6	45·0	94	− 20	34	51	226	99	410	6·0
Zabkowice	50 21	19 14	984	26·8	48·4	60·4	44·4	45·0	89	− 8	76	116	231	193	616	7·0
Tarnopol	49 33	25 36	1043	23·5	46·6	62·4	44·2	43·9	89	− 13	43	141	293	132	609	6·4
Jagielnica	48 56	25 45	1030	23·5	46·4	64·2	44·8	44·4	90	− 13	49	128	247	128	552	5·8

* Means of the highest max. and of the lowest min. each year.

TABLE II.—PERCENTAGE FREQUENCY OF WIND DIRECTION.

STATIONS.	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm.
	%	%	%	%	%	%	%	%	%
BIELSKO—									
Winter . .	14	10	9	2	22	6	31	6	...
Spring . .	13	11	5	3	24	8	25	11	...
Summer .	10	8	10	3	23	10	26	10	...
Autumn .	13	8	6	7	23	10	23	10	...
Year . .	13	9	8	4	23	8	26	9	...
PINSK—									
Winter . .	8	2	9	11	16	17	23	7	7
Spring . .	7	14	21	19	10	4	12	8	5
Summer .	10	3	3	6	11	7	30	22	8
Autumn .	4	6	14	9	11	7	25	14	10
Year . .	7	6	12	11	12	9	23	13	7

where summer is warmer but winter much colder than in the west. The average rainfall is 400-600 mm., also decreasing eastwards, but is generally heaviest at places like Pinsk, on the edge of great swamps. Cloudiness is least in summer, greatest in autumn and winter. The prevailing wind is West, locally South-west, but calms are frequent. C. E. P. B.

Observations at 62 Camden Square.

In March 1922, when the Headquarters of the British Rainfall Organization were transferred to the Meteorological Office at South Kensington and the care of the meteorological station at Camden Square was entrusted to the Society, it became necessary to make arrangements for the continuance of the meteorological observations which were commenced by Mr. G. J. Symons in 1860.

At the time of the transfer the Council were glad to accept an offer from the Headmistress of the North London Collegiate School for the observations to be taken by the senior pupils, under suitable supervision, and this arrangement continued with satisfactory results until the beginning of last May. The pupils of the school took much interest in the work, and certain of the readings were posted up daily in the school premises.

It was felt, however, that the permanence of the work would be better ensured if the observations could be placed under the charge of a public body, and arrangements have now been made for the observations to be undertaken by the St. Pancras Borough Council. Two members of the staff of the Medical Officer of Health for St. Pancras have been appointed as observers, and have taken the readings since the beginning of May.

It is hoped that the action of the Borough Council in permitting their staff to undertake the work will ensure the continuity of this unique London record.

DAILY AVERAGE MINIMUM AND MAXIMUM TEMPERATURES, GREENWICH, 1841–1922.

Date.	January.		February.		March.		April.		May.		June.		July.		August.		September.		October.		November.		December.	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
1	33·74	42·86	34·30	43·94	34·69	47·29	36·69	54·73	40·70	59·58	46·78	69·26	51·13	71·36	53·34	73·84	50·42	69·88	46·28	63·99	41·61	53·27	35·62	45·49
2	34·26	43·01	33·54	·96	·68	·87	·83	·89	·68	·66	48·06	·82	52·01	72·19	52·72	·58	51·10	70·04	45·91	62·13	·04	·11	·84	·34
3	·45	·52	34·30	44·39	·48	·33	37·52	55·38	·44	60·77	·73	·96	·78	·87	·47	72·88	·08	·02	46·28	·75	40·10	52·54	36·14	46·44
4	·13	·24	·28	·11	·30	48·07	38·04	·34	41·06	·14	·34	·99	·44	73·18	53·30	73·52	50·73	69·59	·32	·06	39·48	·49	·90	·17
5	33·56	·03	·56	·38	·82	·71	·20	·28	40·81	62·47	·82	·56	·36	·93	·21	·54	·87	70·23	·37	61·39	40·53	·59	37·59	·90
6	·22	42·66	35·12	·76	35·84	49·18	·34	·66	42·24	·14	49·19	68·74	·62	·86	·74	72·86	·71	·31	45·86	60·58	39·62	51·97	·47	·80
7	·44	·76	34·69	45·03	·09	48·48	·63	·60	·08	·03	48·71	·74	·94	72·99	·31	74·19	·43	·12	46·04	61·47	·17	·19	·03	·04
8	34·07	·91	·14	44·82	·19	·32	·66	·59	·16	61·44	·87	69·04	·14	·96	54·06	73·87	51·06	69·99	45·52	60·76	·14	50·97	·58	45·80
9	·23	43·16	33·50	43·95	34·64	·32	·11	54·90	·38	62·02	49·12	68·94	·53	73·53	53·92	·64	50·91	·11	44·66	59·80	38·80	·44	35·40	·17
10	33·97	·23	34·03	44·86	·44	·37	·24	·94	·39	61·86	·01	·39	·31	·47	·36	·68	49·97	67·94	·88	60·07	37·98	49·98	·72	44·43
11	34·07	42·49	33·62	·24	·24	·56	37·42	55·23	·28	63·53	48·27	69·57	·46	·69	·32	·47	48·54	68·42	·96	59·37	38·03	·63	34·58	·23
12	33·22	·32	32·29	·41	·09	·91	38·41	·49	43·83	64·01	49·27	·22	·84	74·28	·23	74·13	49·18	·87	43·58	·24	37·71	·34	35·36	·51
13	·51	·99	33·34	·64	·67	·56	·43	·51	·83	63·63	·46	·90	53·14	·87	54·21	·46	48·87	67·91	42·96	58·14	·81	·39	36·46	45·56
14	34·16	·80	34·47	45·34	35·29	49·35	·26	·73	·86	·69	·16	·30	·81	75·09	·27	·38	50·04	66·94	43·32	·08	·72	·16	·68	·79
15	33·92	·68	·94	·24	34·98	48·94	37·98	56·79	44·04	·78	·01	·62	·91	·23	·28	73·35	49·63	67·20	·22	57·93	·02	48·56	·70	·58
16	·81	43·26	·58	46·44	35·96	50·09	39·07	·12	43·64	64·10	·39	70·80	·36	74·29	53·04	·31	·32	·73	·54	·43	·38	47·92	·10	·59
17	34·16	·06	·69	47·04	·94	·21	38·88	57·00	44·63	63·49	·26	·59	54·28	·73	·72	72·86	·99	·91	42·97	58·17	36·69	·38	·54	44·74
18	·17	44·03	·24	46·08	·11	·41	·92	·38	·04	64·28	·24	·41	53·87	·60	·59	·37	48·74	66·77	43·04	56·84	·62	·42	35·70	·99
19	·16	43·51	·72	45·63	·52	·02	39·21	58·76	43·97	·63	·97	71·10	·31	73·99	·59	·14	47·93	65·74	·37	·88	·59	·60	34·58	43·88
20	·44	·16	·49	·28	·98	49·68	·14	59·83	·99	·77	50·49	70·66	·60	74·21	·32	71·61	·80	·63	42·72	·14	37·24	·09	·26	·12
21	33·96	42·68	·48	46·11	34·69	·71	·74	·26	44·86	66·06	·74	71·94	54·02	73·97	52·87	72·02	·06	64·94	41·85	55·81	36·16	46·86	·70	·36
22	·70	·79	·86	·49	·33	50·16	40·26	58·38	45·89	·93	51·37	72·51	·59	74·72	·21	·59	·51	65·04	·78	·63	·69	47·41	·34	·43
23	·41	43·04	·64	·46	35·14	·78	39·52	·90	46·33	67·74	·21	71·82	·51	73·13	·22	70·99	·63	64·82	·82	·18	·67	·18	33·46	42·69
24	·71	·22	·64	·10	·24	51·86	·41	·57	·33	·46	·43	·93	53·66	·27	·10	71·86	48·17	·94	·41	·01	·25	46·79	·34	·87
25	·90	·91	·76	·96	·74	·29	·96	·41	·31	·49	·48	·18	·31	·58	51·79	·54	47·04	65·37	40·94	54·20	·37	47·06	·36	·94
26	·92	44·27	35·29	47·13	·74	50·77	·58	·92	·68	·12	·23	·94	·48	·71	52·29	·11	·28	·24	·91	53·92	·93	46·92	34·56	43·13
27	34·36	·81	34·82	46·64	·78	51·59	40·21	59·19	·47	68·11	·38	73·16	·53	·31	·67	70·78	46·98	64·94	39·79	·67	·60	·42	·54	·63
28	·28	·67	·56	47·14	36·07	·96	·46	·27	47·10	67·47	52·37	·54	·38	72·96	·22	71·66	47·72	·31	40·86	54·34	·81	·78	·86	44·11
29	·49	·69	36·28	·09	37·10	52·76	·10	58·68	·06	68·20	51·64	72·86	52·89	73·76	51·99	70·58	·18	63·79	·93	·06	·42	·62	35·17	·44
30	·76	·64	...	...	36·56	53·06	·18	59·67	·00	·56	·33	·01	53·56	·69	·19	·84	46·68	·29	·59	53·76	35·80	45·57	34·88	43·68
31	35·28	·61	...	...	37·21	54·33	...	...	46·94	·36	...	...	·54	74·08	50·96	69·97	...	...	41·06	·71	...	...	·37	·34

Greenwich Average Daily Temperatures, 1841–1922.

Average daily minimum and maximum temperatures for Greenwich, for the eighty-two years 1841–1922, have been worked out by Mr. John Dover, F.R.Met.Soc., of Totland Bay, I.W., and are published in his Annual Meteorological Report for 1922. They are reprinted in the *Journal* with the sanction of the Astronomer Royal and of Mr. Dover, since it is thought that they will prove of interest to many Fellows. They are deduced from readings of thermometers exposed in a Glaisher thermometer stand.

The lowest temperature recorded during the period was 4°·0 F. on January 9th, 1841; the highest reading was 100°·0 F. on August 9th, 1911. The lowest temperature since 1890 occurred on February 8th, 1895, when a reading of 6°·9 F. was registered.

OBITUARY.

Mortyn de Carle S. Salter.

All Fellows of the Society will have heard with extreme regret of the untimely death of Mr. Mortyn de Carle Sowerby Salter, which occurred after a brief illness on May 21, and will wish to express their sincere sympathy with Mrs. Salter and other members of his family in their bereavement. Salter was one of the few who have devoted themselves to the development of one particular branch of our science. He joined the staff of the British Rainfall Organization in 1897, at the early age of seventeen, and there received a thorough grounding in what was to be his life-work, under the guidance, first of G. J. Symons, and later of Dr. H. R. Mill. The seed fell on receptive soil, and from 1911 onwards we have had a steady flow of papers from his pen, either singly or jointly with others, in the *Quarterly Journal*, in the volumes of *British Rainfall*, or in the technical press dealing with water supply. As befits a disciple of H. R. Mill, Salter was greatly attracted by the cartographic method of exhibiting rainfall results, and much of his work was on those lines. He was therefore keenly interested in the preparation of the maps of average monthly rainfall over the British Isles, which it is intended to include in the Society's Climatological Atlas. The methods used in constructing these maps are familiar to Fellows from a joint paper by Dr. Mill and Mr. Salter on "Isomeric Rainfall Maps of the British Isles," which appeared in the *Journal* in 1915, and from a later paper by Salter alone on "A New Method of Constructing Average Monthly Rainfall Maps" (1921). The work is now completed, but an opportunity of publishing it in fitting form has still to be found. When it presents itself we shall have a lasting memorial to Salter's share in bringing to a successful issue this important co-operative enterprise. The work on these maps led up directly to a paper, jointly with J. Glasspoole, on "Fluctuations in Annual Rainfall considered Cartographically," read as recently as May 16, when Salter was already stricken by the illness which was to prove fatal. Among other papers we may recall one on the "Relation of Rainfall to Configuration," which appeared in the *Transactions of the Institution of Water Engineers* in 1918, and won the President's premium, and one on the "Exposure of Rain-gauges," read in 1919 at a conference of delegates of Corresponding Societies of the British Association and subsequently printed in *British Rainfall* for that year. Both were on subjects in which Salter had made himself an expert.

Few who have not taken a share in the preparation of meteorological statistics on a large scale can realise the enormous volume of persistent work that has to be got through if an organization such as "British Rainfall" is to prosper. Hard work of that kind had no terrors to Salter. In 1913 he became associated with Dr. Mill as Joint-Director of the Organization. In the following year the war broke out and made a further call on his energies. Rejected from military service for reasons of health, he devoted himself with redoubled energy to carrying on the work of the Organization. In spite of a reduced staff he and Dr. Mill succeeded not only in keeping together the corps of voluntary observers but in carrying through the publication of the annual volumes with but slight reduction in bulk—all the essential tables were retained—and with only trifling delay. It was a notable achievement. In conversation Salter was never tired of acknowledging the help he received during those years from friends interested in the work, more especially from the remaining members of the staff, but it was largely his personal example and enthusiasm, and that of Mrs. Salter, which induced others to give their time and energies.

After the close of the war the Rainfall Organization became attached to the Meteorological Office, and the years since 1919 have been devoted on the administrative side to working in the traditions and procedure of the Organization with the more rigid system of a State service, a task that presented many minor difficulties and called for the exercise of much tact. Despite these preoccupations Salter found time to set out the work of the Rainfall Organization and the results it has achieved in most readable form in "The Rainfall of the British Isles," which appeared in the summer of 1921.

He was elected a Fellow of the Society in 1905, was a regular attendant at the meetings, and served on the Council from 1910 to 1921. He will be much missed by all who knew him, and not least by those of us who had the privilege of working with him as a colleague at the Meteorological Office.

R. G. K. L.

Mr. F. W. Harmer, F.G.S.

On April 24, within a few days of the completion of his eighty-eighth year, occurred the death of Mr. Frederic William Harmer.

Mr. Harmer came of a well-known Norfolk family, and from his early youth evinced a great love for science, particularly for geology. East Anglia was the field of much of his research work, and to his patient investigation and untiring energy many facts of much geological importance were brought to light. He elaborated an interesting discussion on the meteorology of the Pliocene and glacial periods.

Mr. Harmer was elected a Fellow of this Society on March 15, 1905.

REVIEWS.

The Evolution of Climate. By C. E. P. Brooks, M.Sc., F.R.A.I., F.R.Met.Soc., with a preface by G. C. Simpson, D.Sc., F.R.S. London (Benn Bros. Ltd.), 1922. 8°. Pp. 174. 8s. 6d. net.

Mr. Brooks's researches on the quantitative effects of continentality on temperature are well known to readers of this *Journal*. We now have their application to the solution of the old problem, the causes of glacial periods. Changes of climate are believed by the author to be due mainly to changes in the extent of the land areas, especially in temperate latitudes, astronomical changes, whether in the sun or the earth, being of little importance; investigation must be based on geology. This view is not new, but Mr. Brooks is unusually well-equipped for its exposition owing to his wide acquaintance with geological literature—he might well claim that his work is geology rather than meteorology. And the flashes of direct human interest drawn from the life of primitive man illuminate pleasantly many a page which might possibly have been drab; such references as that to the fur-clad Mousterian men shivering in their caves are an effective break in a severely geological narrative.

In his preface Dr. Simpson makes some pertinent remarks on the difficulties of the general problem. "One will not be satisfied with an explanation of the Great Ice Age which does not explain at the same time the records of earlier ice ages." Most of the well-known explanations have failed to stand the test of time in spite of early popularity. We cannot help feeling that Mr. Brooks admits a weakness when he is driven to invoke the theory of drifting continents to explain the Permo-Carboniferous glaciation, making the lands concerned break off from Antarctica and drift northward to the Tropics to puzzle observers by the traces of the action of the vanished ice. But can we yet demand a detailed explanation of those remote glaciations? The geological record is incomplete and largely unexplored, and authorities are not in complete agreement as to its interpretation. We venture to think that this is a possible key to the difficulty which Mr. Brooks frankly admits in offering his explanation.

But the greater part of this book deals with the Quaternary Glaciation. Mr. Brooks calculates theoretically the temperatures for the land areas which geological evidence has established for various epochs, and shows a striking agreement with the temperatures deduced by Penck and others from the nature of the ice-sheets. This is certainly a vindication of the formulæ which Mr. Brooks based on the present relations between temperature and continentality; and they are strictly applicable, since the general distribution of land and sea was similar to the present. But it would seem doubtful how far they would hold for remoter times, when land and sea were very differently arranged, and in particular ocean currents may have been very different. Mr. Brooks does not seem to allow sufficiently for this last point. Thus he postulates for early Tertiary times (page 44) three ocean currents analogous to the Gulf Drift feeding a great warm ocean in the Arctic regions. Are we justified in assuming that the three openings in the Arctic basin at that time would necessarily—or even probably—have each admitted a drift similar to the Gulf Drift of to-day, which is itself unique, the result of several peculiarities of arrangement of land and sea which we can hardly assume without more evidence to have been repeated for each of the three inflows?

A chapter is devoted to each of the continents, giving a masterly summary of the late geological succession of climates down to the present time. We greatly admire the imagination which is brought to bear on the interpretation of the geological facts. A living and convincing picture is built up, in which each part of the world fits in an orderly way.

Mr. Brooks has done a most valuable and useful work in bringing together, correlating, and interpreting the results obtained by many workers, including himself, in specialised fields. Possibly he tends to accept hypotheses somewhat too readily, but a bibliography at the end of each chapter enables us to refer to the originals and draw our own conclusions.

It is a pleasant change, after much literature that has appeared on this subject, to have detailed geological evidence, most of it of a definite and tangible kind, produced in support of almost every paragraph in the story of the changes of climate which we are asked to accept. W. G. K.

The Evolution of Climates. By MARSDEN MANSON. Baltimore, Md. (The Lord Baltimore Press), 1922. 8°. Pp. 66.

Mr. Manson sets out to find a theory of changes of climate which shall hold good for all known instances. His main idea is that the present solar control and resulting zonal arrangement of climates are quite abnormal; during most of geological time the heat of the atmosphere was derived from the earth itself, "made available by deformations and ruptures of the crust, . . . the erosion of warm crustal materials and the exposure and transformation of radioactive substances." The heat was conserved by the dense clouds formed from the masses of vapour which the oceans poured into the air. Solar control was negligible, temperature was nearly uniform over the whole globe. But the heat was gradually dissipated, and at length the cloud canopy became so attenuated that, though the oceans were still covered, the land masses enjoyed fairly clear skies, and began to cool more and more rapidly by radiation till ice-sheets formed; for the cloudiness was still sufficient to intercept the solar heat. In Permo-Carboniferous times the cooling was most rapid in sub-tropical latitudes where, owing to the existence of anti-cyclonic conditions as at the present time, the cloudiness was least and radiation most intense. Thus were formed the ice-sheets of which we have the record in the Dwyka formation of S. Africa and elsewhere. The glaciation was denied further extension by a new outburst of terrestrial heat.

Since Tertiary times the liberation of terrestrial heat seems to have stopped, and even the oceans have cooled greatly, so that the cloud canopy is now very incomplete. The Pleistocene glaciation occurred in the belts of maximum precipitation. But the continued decrease of cloudiness finally allowed the sun's rays to be an effective source of heat at the surface of the earth, so effective that the ice disappeared from temperate latitudes, and is still in retreat in the polar regions; and we have to-day the novel zonal arrangement of climates, with greater differences of temperature with latitude than have ever existed before.

It is a bold hypothesis, and Mr. Manson works it out logically and with much detail, but from its nature proof would be difficult, and indeed none is attempted. The justification claimed is that no other theory can possibly explain the series of geological climates. Mr. Manson's contention is that "no glaciation has been recorded conformably to solar control."

W. G. K.

The Air and its Ways. The Rede Lecture (1921) in the University of Cambridge, with other contributions to Meteorology for Schools and Colleges. By Sir NAPIER SHAW, Sc.D., F.R.S. Cambridge University Press, 1923. 8°. Pp. xx + 237, pls. 28. 30s. net.

This book consists of fifteen essays on meteorology and many plates and figures, the subjects dealt with covering a wide range. They include such diverse matters as Meteorology for Schools and Colleges, Units of Measurement, the Drought of 1921, and Artificial Control of the Weather. The plates give the most recent information concerning pressure, temperature, and other meteorological elements over the globe, and there are illustrations of clouds. Some of the curves and figures show the latest information about upper-air temperatures, pressures, and winds. The essays are all interesting, and, as anything from Sir Napier Shaw is bound to be, instructive: they can be read and enjoyed by any one possessing a moderate knowledge of mathematics and physics.

In the preface the author claims the introduction of three new meteorological principles: firstly, "the motion of air under balanced forces as an effective representation of the actual conditions"; secondly, "the 'eviction' of air by the turbulent motion between rising air and its environment, as an inevitable concomitant of convection"; thirdly, "the effective stratification of successive layers of air in consequence of the resilience which they owe to the excess of their temperature over that which corresponds with unlimited miscibility, and the limitations which are due thereto."

The first principle—which may be stated in other words by saying that the direction of the wind is a tangent to the isobar, and the velocity of the wind, after allowing for curvature, is inversely proportional to the distance between two consecutive isobars—is generally accepted as a good approximation to the truth. Sir Napier gives plainly and convincingly the evidence in its favour and discusses how close to exactness the approximation is. There is considerable divergence close to the earth's surface, where friction is effective, but above a height of half a kilometre the difference is not beyond the casual error of the observations. Meteorologists are indebted to the author very largely for the introduction of this principle, and the claim he makes for the simplification it has caused is fully justified. It remains for future observations and improved methods to show the precise degree of exactness.

The second principle is not so generally accepted, and pages 91 to 99 are occupied in answering objections made to it. It was communicated to a sub-committee of the Aeronautical Research Committee in a paper on The Cyclonic Depressions of Middle Latitudes.

The principle is, that a mass of warm air rising in consequence of its lightness, carries with it some of the circumadjacent air which is "evicted" from the strata through which it passes in the central part of the cyclone; and the inflow of air from the outer part, supposing there is sufficient vorticity to start with, will produce a great increase of wind in the central part, according to the dynamical law of equal areas in equal times. This may certainly be the case in tropical hurricanes, but in the European cyclone the reviewer doubts if there is sufficient warm air to produce the effect, since the central parts of such a cyclone are admittedly cold from the first half kilometre upward to the stratosphere.

The third principle is that of resilience. This is a very convenient name for a fairly obvious process, and we hope it may be generally adopted. It depends on the general stability of the air and its ability to oppose vertical motion. Most parts of the atmosphere are arranged in layers as though the upper of any two adjacent layers were of less specific gravity than the lower layer. This is due to the fact that the potential temperature in general increases with increasing height, so that rising air soon becomes too cold and therefore too heavy to rise further, and sinking air too warm to sink further.

The ordinary lapse rate of potential temperature for the troposphere is about 4° C. per kilometre, and for the stratosphere it is 10° C. The change of 10° C. alters the density by about 4 per cent, so that if air rises one kilometre in the stratosphere, it is equivalent to adding 4 per cent to its density. Hence the resilience. Sir Napier calculates that the resilience in the stratosphere is about one ten-thousandth part of that provided by the sea at the bottom of the air column. It is of the same nature. But there is one point that must be noticed: the resilience depends upon an adiabatic change of temperature, and if the change of height occurs too slowly it will not be adiabatic, because the result will be influenced by radiation. Radiation may perhaps produce changes of temperature in a layer of air of the order of 3° C. per day, so that the resilience may be greatly reduced for slow changes of level.

In the second essay Sir Napier discusses the important and controversial question of the best units of measurement, and his opinion is strongly in favour of millibars for pressure, of the absolute scale for temperature, and millimetres for rainfall. He points out that it is not consistent to measure pressure in units which denote only a length, and also how convenient it is that 1000 mb.

is quite close to the average surface pressure, so that departures from the mean are readily expressed as percentages. With regard to temperature, the absolute scale has the great advantage of requiring no minus signs, and is most convenient for any one who has to use the gas equation in theoretical work. There seems a hopeful prospect that these units may become general.

The third essay is on The Meteorology of the Globe in 1911. It contains a description of the *Réseau mondial*, which was first published for the year 1911. When we remember that the original observations are given in different units and half of them have to be transposed, it is no wonder that the author of this book, who was responsible for the publication, should strongly advocate uniformity of units in meteorological literature.

Essays 5 to 9 are more or less occupied with the discussion of the general circulation and the mechanics of cyclones and anticyclones. It is refreshing to find that the whole available information about the upper air is incorporated into the discussion. These chapters are most interesting and suggestive, but it is not possible in a short review to refer to many of the points raised.

On page 136 Sir Napier gives a note on the prevalence of convection in the atmosphere; he uses the term "penetrative convection," and comes to the conclusion that it is comparatively rare, perhaps one case in fifty. But the question arises, should the term convection include all cases of the transfer of heat by moving masses of air—the transfer of heat, for example, from the equator to the pole? In meteorological literature the term seems generally to refer only to the transfer of heat upwards by the rising of warm air.

In this same note Sir Napier discusses the flow of heat downwards in the atmosphere by mixing, the so-called turbulence or eddy conductivity. This flow downwards undoubtedly occurs, whether the mixing be caused by the general circulation or by local disturbance. There are three means by which heat can flow vertically in the atmosphere: (1) by the transfer of latent heat in the water vapour; (2) by convection in the fullest sense of the term, and (3) by radiation. With temperatures below zero F. (1) is practically non-existent, and (2) and (3) must have opposite signs and on the average cancel each other out.

Essay 12 is on The Law of Sequence in the Yield of Wheat for Eastern England. It contains the discussion of a very remarkable coincidence, if it be a coincidence, and should be read by every one interested in statistical data. The curve from 1885 to 1905 is almost perfectly symmetrical about its middle point, so that when turned through two right angles and fitted in this reverse position on itself, the fit is almost perfect.

Essay 13, on Meteorology and Agriculture, deals with various elements of weather and contains a list of Hooker's correlation coefficients. It appears that a cool late spring and early summer is favourable to nearly all the usual farm crops.

Essay 15 is on The Artificial Control of the Weather. The author shows that mankind might perhaps hope to influence the weather if he could work to that end on a sufficiently large scale, but that the natural scale of operation is so immensely large that any influence he may exert is utterly insignificant in comparison, and that control of the weather as a practical proposition is perfectly hopeless. One may be pardoned for thinking that it is fortunate that it is so.

This is a book that should be read by every meteorologist, and parts of it will be found of interest also to the general public. W. H. Dines.

QUARTERLY JOURNAL

OF THE

ROYAL METEOROLOGICAL SOCIETY

VOL. XLIX.] OCTOBER 1923 [No. 208

THE FLUCTUATIONS OF ANNUAL RAINFALL IN THE BRITISH ISLES CONSIDERED CARTOGRAPHICALLY.

BY M. DE CARLE S. SALTER, Superintendent, British Rainfall Organization, and J. GLASSPOOLE, M.Sc., A.I.C.

[Received February 7—Read May 16, 1923.]

THIS paper deals with only a part of a general investigation into the secular variation of rainfall in the British Isles during the last half-century, made possible by the recent computation of a large number of average values for the period 1881–1915.[1] A preliminary discussion of the mean and extreme percentage fluctuations, by Mr. Glasspoole, has already been published.[2] The inquiry has now been carried a stage further by the construction of a series of maps showing the percentage departure from the average in each year for all parts of the country.[3] It has been possible to extend the series back to 1868, giving, up to 1921 inclusive, 54 consecutive years. The number of records used for each map varied from about 150 to 250, selected so as to represent all parts of the British Isles as equably as possible.

Previous investigations into the secular variation of rainfall in this country have apparently been confined to definite localities, usually dealing with the records at individual stations; except that since 1904 maps similar to those now discussed have been published annually in *British Rainfall*, following a series of diagrammatic maps prepared year by year by the late Mr. Symons. The method of studying fluctuations of rainfall from individual stations presents the intrinsic disadvantage that the station selected may not represent what is happening generally, or may do so only in a partial manner. In addition to this, investigations based on individual records provide no automatic check on accuracy or homogeneity. The geographical variation of rainfall is in some places so abrupt that a slight change in the position of a gauge may introduce a serious discontinuity. By utilizing numerous records a check is kept on the various errors which so often affect rainfall records.

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[1] See *Q.J.R. Meteor. Soc.*, **46**, 1920, pp. 254-271.

[2] See *British Rainfall*, 1921, pp. 288-300.

[3] These maps, together with similar maps for each 10-year period, and the resultant general percentage values, were prepared by J. Glasspoole.

NATURE OF VARIATIONS.

It has long been apparent that the fluctuations of rainfall in the British Isles are of two kinds, *i.e.* in the amount of the fall and in the type of distribution. It is impossible to form any sound conclusion as to the underlying causes of the first without taking the second into account. It is indeed probable that of the two the second is the more important, since it appears that the variations from place to place within the country are of greater magnitude than the general fluctuations affecting the whole country.

In 1905 Dr. H. R. Mill undertook the onerous task of constructing a series of maps showing the distribution of total rainfall in each year as far back as sufficient data were available.* The series extends back to 1854 and is now kept up to date as part of the ordinary routine of the British Rainfall Organization; but, except in the case of one or two years of outstanding interest, none of the maps prior to 1919 have been published. The study of these maps has been of great value in forming our ideas as to the factors controlling the distribution, and the nature of the variations from year to year.

From isohyetal maps alone it is not, however, easy to grasp the full significance of secular variation. At a first impression annual rainfall maps for different years appear very much alike. This family resemblance arises from the strong orographical control and the overwhelming preponderance of precipitation from westerly and south-westerly quarters. Fig. 1, showing the average rainfall for a period of 35 years, indicates the prevailing type of distribution.

The percentage maps show the relation of the fall in individual years to that in the average year, thus cancelling out the complex distribution due to local configuration. The percentage variations are never very abrupt, so that lines can be drawn from comparatively few data. These maps show that the resemblance between the annual isohyetal maps of actual fall is only skin-deep, since individual years looked at from the point of view of their relation to the average present profound differences from one another.

Rain in temperate climates may be broadly regarded as being of three kinds—convectional, cyclonic, and orographical; but this is not a complete statement of the case. These three types are not separate and distinct, but most commonly occur in conjunction with one another, individual showers perfectly true to type being comparatively rare. Highly developed convectional rains, although sometimes very heavy, are nearly always extremely local. Their effect on the percentage maps is to introduce minor irregularities; and their influence in modifying the general distribution during any individual year may be regarded as negligible. We may thus look upon cyclonic and orographical rains as the predominating factors. Of the two, cyclonic rains are probably the more important in determining the type of distribution as brought out by the percentage maps. Orographical rain operates less as a distinct type than as a modifying tendency. Thus, although very strongly developed cyclonic rains are undoubtedly independent of the configuration of the land, in the majority of cases maps of cyclonic rain-showers show more or less bias towards an orographical distribution; and it is impossible to draw any strict line of demarcation between the two types, which gradually merge one into the other.

Bearing these generalizations in mind, it appears probable that the characteristic types of distribution which we may expect to find in the percentage maps for individual years will be (i.) that in which the orographical tendency is at a maximum, giving excess in those regions where orographical rainfall is most effective; (ii.) that in which orographical rainfall is subnormal, giving a minimum in these regions; and (iii.) that in which highly developed cyclonic rain is most frequent. Figs. 2, 3, and 4 give characteristic examples of these three types.

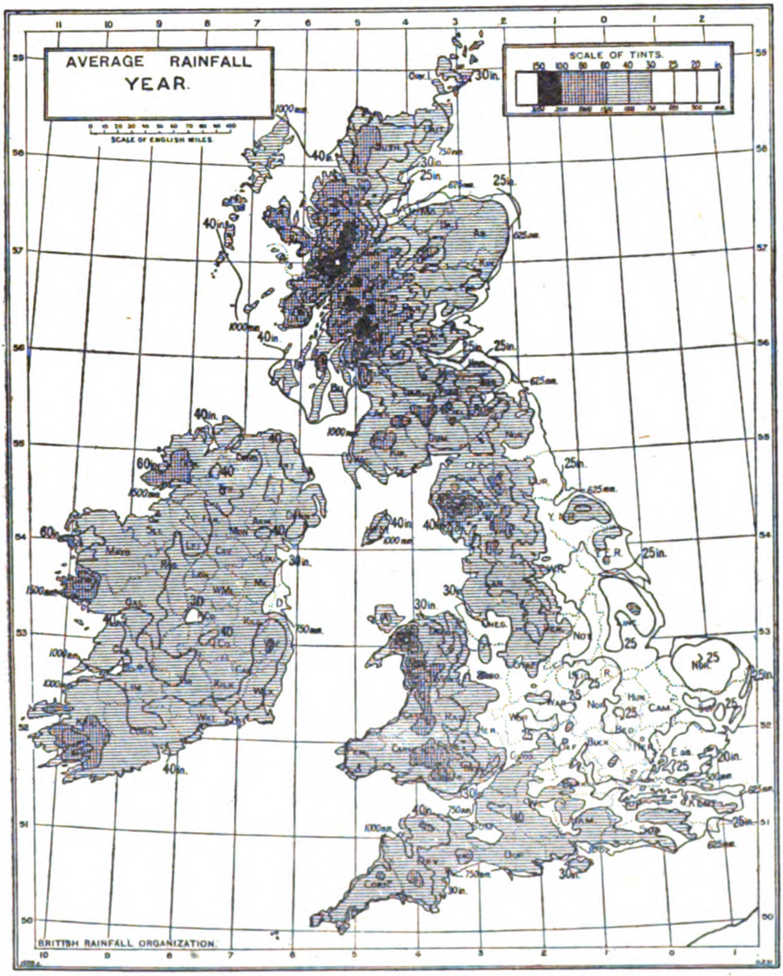
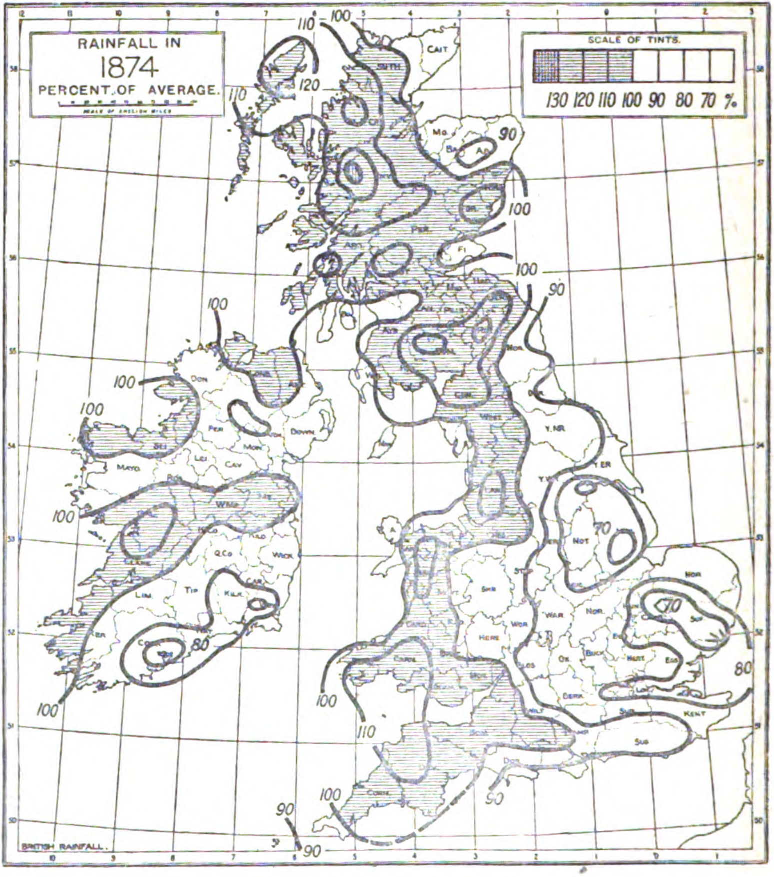


FIG. 1.—Distribution of annual average rainfall for 35 years.

It will be observed that the type of distribution shown in Fig. 3 is no doubt indicative of a year in which cyclonic rains were more highly developed than is normally the case. It does not necessarily follow that they were much more frequent or more heavy than usual, as in Fig. 4. Figs. 3 and 4 therefore represent not different types, but modifications of the same type.

In attributing excessive rainfall in the mountainous districts of the west to supernormal orographical effect it is assumed that comparatively little orographical rain is produced by East wind. There is undoubtedly an orographical tendency in the rainfall distribution with winds from the sea in the south of England, but it is slight compared with that in the west, whilst in the east it is nearly negligible.

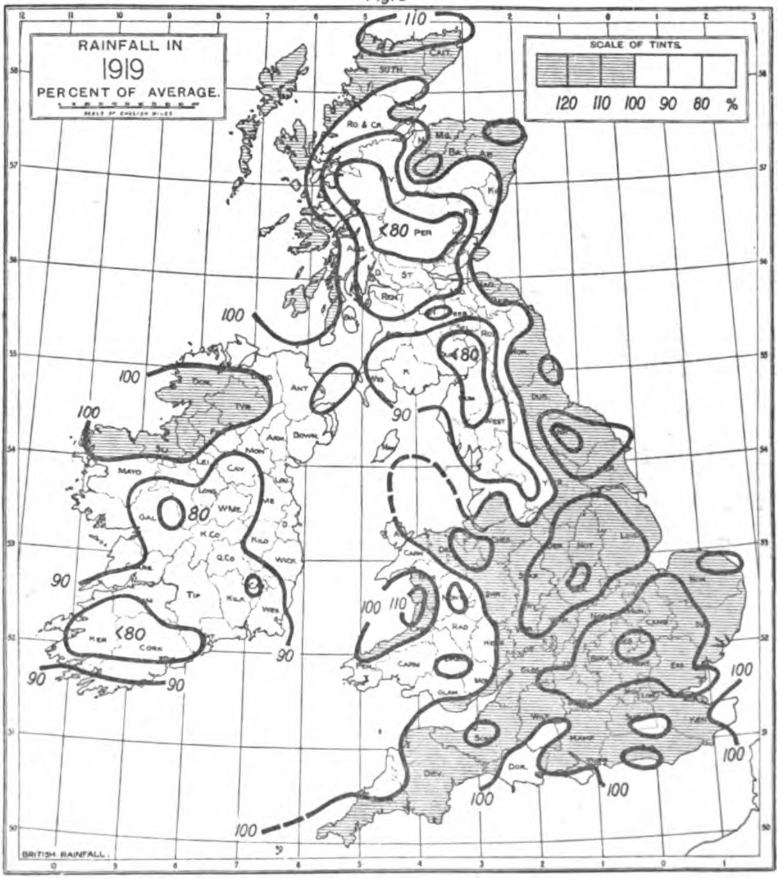
Fig. 2.



Range of Variation.

The maps emphasize the fact that the expression "average rainfall," when applied to the distribution, as well as to the amount, refers to a condition which never actually exists. Of the whole series of 54 years none shows a distribution closely resembling the average. The range of deviation met with is shown to be larger than had previously been supposed.[1] In every year of the series some part of the country had more than its average rainfall, and in all but three years some part had less than its average. The smallest range between the wettest and the driest spots, relatively to the average, was 35 per cent, the largest 80 per cent, and the mean 45 per cent (see Appendix, Cols. 3, 4).

Fig. 3



The greatest excess at any individual station was 80 per cent at Osmotherley near Northallerton in 1872, this figure being well supported. The greatest deficiency was 59 per cent at Margate in 1921: numerous stations in the south-east of England showed deficiencies of 50 per cent in that year. The greatest range at any one station was about 110 per cent, and the smallest about 40 per cent. Taking the wettest spot in each year, relatively to the average, the mean excess was 28 per cent, whilst the mean deficiency at the driest spots was 21 per cent. The amplitude of the range in any individual year does not appear to bear any definite relation to the general rainfall of that year; but it is evident that the range is determined by high maxima rather than by low minima.

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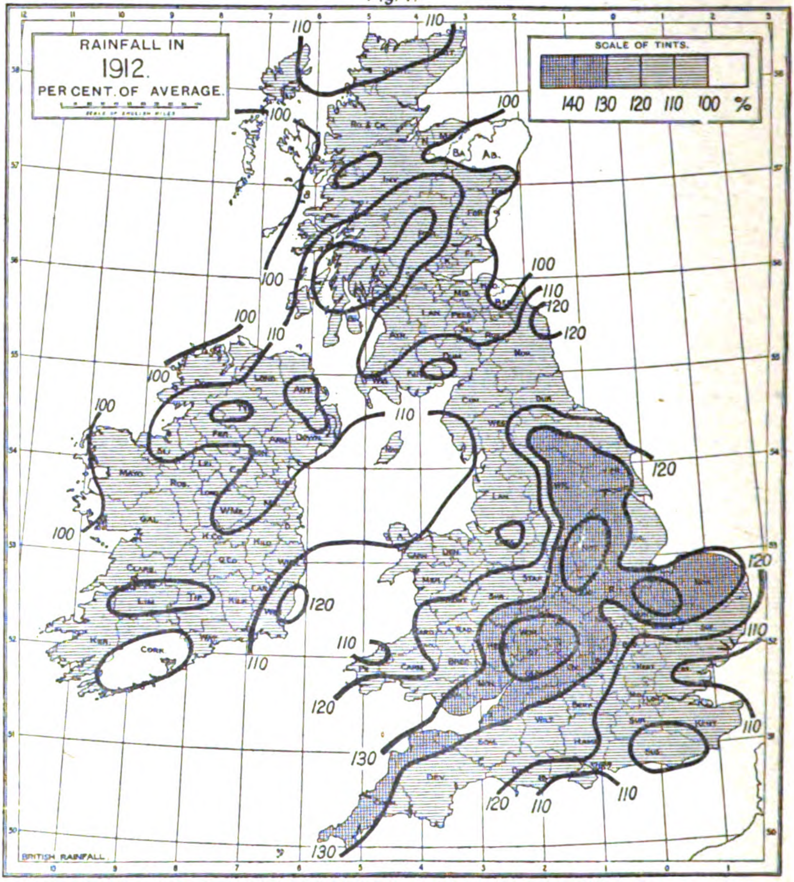
[1] G. J. Symons, *British Rainfall*, 1883, p. 32; Sir Alexander Binnie, *Proc. Inst. Civil Engin.*, **109** (pt. 3), 1891-92; H. R. Mill, *Proc. Inst. Civil Engin.*, **155** (pt. 1), 1904.

Fig. 4.



GEOGRAPHICAL DISTRIBUTION OF VARIATIONS.

The correlation between the fluctuations at adjacent stations is high. In order to test how far this holds good for more distant stations, dot diagrams were constructed for the following pairs of records for places remote from one another:—

(i.) Tenterden (Kent). Glenquoich (Inverness).
(ii.) Wick (Caithness). Killarney (Kerry).
(iii.) Glenquoich. Killarney.
(iv.) Tenterden. Wick.

There was a slight positive correlation between Tenterden and Wick, both in the east, but in the other cases there was obviously no connection, either direct or inverse.

In order to make a similar examination based on the general fall over large areas, group-values were computed for the following districts:—

Scotland, East.
Scotland, West.
Ireland, East.
Ireland, West.
England and Wales, East.
England and Wales, West.

There was evidence of some general relationship between the east and west of each country, although it is not very close, being least marked in Scotland. Taking as a single group the westerly stations for all the countries and correlating them with the easterly stations, grouped in a similar manner, the correlation coefficient (r) is $+0{\cdot}64$, with a probable error (e) of $0{\cdot}08$. For the easterly and southerly stations grouped in a similar manner $r = +0{\cdot}85$ and $e = 0{\cdot}04$.

Types of Distribution.

The distributions shown by the maps must represent the resultants of general and local variations; and it would appear that the latter are liable to be of at least as great magnitude as the former. The maps may be roughly classified into groups which may be conveniently designated as—

W. having a preponderance of excess in the west (orographical).
E. ,, ,, ,, east (non-orographical).
C. ,, ,, ,, some other centre (cyclonic).

The most highly developed examples of these are shown in Figs. 2, 3, and 4 above, respectively. In some years, as may be expected, two types appear together in one map, and in others the distribution is too indefinite to admit of classification. In the Appendix (Col. 9) these are marked I. Years with identifiable but weakly or partially developed type are marked with a small initial letter.

There is no very clear alternation in the prevalence of one or other type; but during the 12 years from 1875 to 1886 the type was cyclonic or non-orographical in 10 years and orographical in only 1; whilst in the 11 years 1911 to 1921 there was an orographical distribution in 6 years, and a cyclonic or non-orographical distribution in only 4 years. There is no doubt that a change occurred in respect of the prevalence of the different types. This was clearly shown by the maps for each 10-year period. They show that the easterly or cyclonic type preponderated in the 'seventies (see Fig. 5), and that by the late 'nineties it had given way to a slight preponderance of the westerly or orographical type (see Fig. 6). In the last decade of the series, whilst individual years of marked westerly type were more frequent, there was a tendency for a shift of the areas of high rainfall to the south. In other words, during this period, when the distribution was not westerly, it was more often southerly than easterly (see Fig. 7).

Fluctuations of General Rainfall.

The data from which the maps were constructed enabled general percentage values to be computed for the countries and for the whole

RAINFALL
PER CENT. OF AVERAGE.
1881—1915.

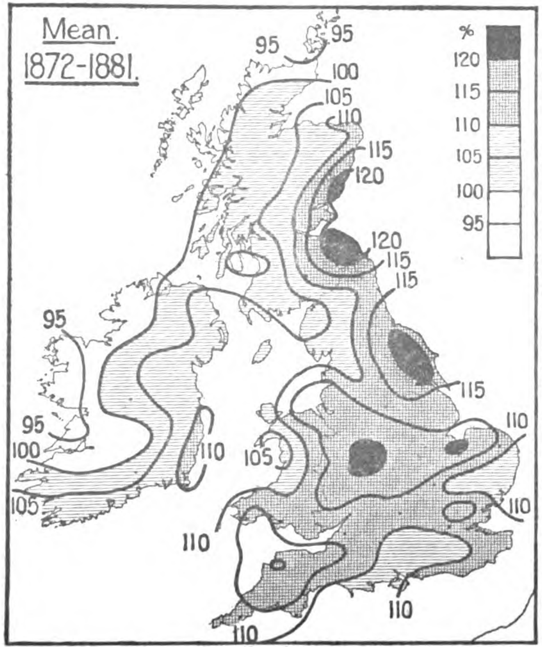


Fig.5.

RAINFALL
PER CENT. OF AVERAGE.
1881—1915.

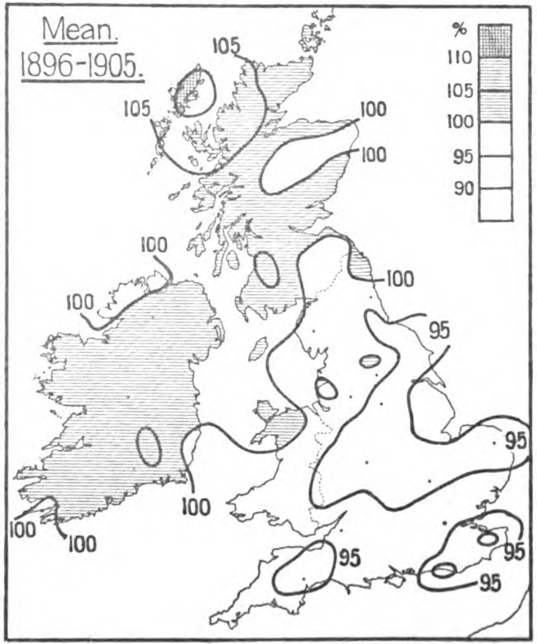


Fig.6.

RAINFALL
PER CENT. OF AVERAGE.
1881—1915.

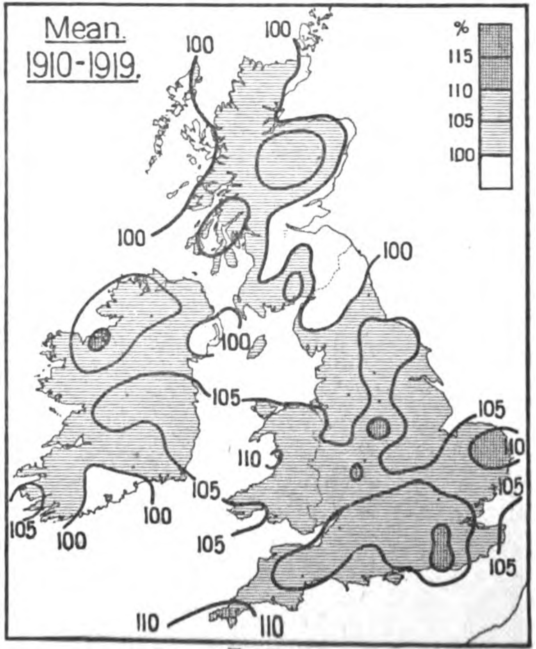


Fig.7.

British Isles. These are probably more accurate than those published from year to year in *British Rainfall*, since the data available were more homogeneous, and since the average referred to is constant throughout. It is unlikely that any individual year's value is in error by more than about 5 per cent.

The yearly percentage fluctuations are represented graphically in Fig. 8. Taking the curve for the whole of the British Isles, the extreme range is 60 per cent, from 137 per cent in 1872 to 77 per cent in 1887. The range is greatest in England and Wales, and least in Ireland. For the British Isles, 26 years out of the 54 had an excess, 2 had exactly the average, and 26 a deficiency. Grouping the annual values in the order of magnitude, it is seen that departures exceeding 20 per cent occurred in only 5 years.

Per cent . .	Less than 80.	80-89.	90-99.	100-109.	110-119.	120-129.	More than 129.
No. of years .	1	5	20	18	6	3	1

The standard deviation for the whole 54 years was 11 per cent and the mean deviation 8 per cent.

There were 9 consecutive years with rainfall equal to or in excess of the average from 1875 to 1883, but at no time more than 4 consecutive years with deficient fall. From 1868 to 1883 only 4 years out of 16 were dry, and during the following 20 years from 1884 to 1905 there were only 6 wet years. In considering these values it should be remembered that the average was for the 35 years 1881–1915. If the average for the whole period had been used it would have been slightly higher on account of the wet spell in the 'seventies.

During the early part of the series there was a tendency for a repetition of a well-marked maximum at intervals of 5 years. This broke down after 1882. From 1889 to 1903 the period was definitely 3 years, and afterwards 2 years. The repetitions are so striking that it appears worth while to set out the figures :—

5-YEAR PERIOD, 1868–1882.

	1.	2.	3.	4.	5.
	104	102	84	96	137
	94	99	107	113	127
	102	100	102	103	120
Mean	100	100	98	104	128

TRANSITIONAL PERIOD, 1883–1888.

108	94	96	110	77	97

3-YEAR PERIOD, 1889–1909.

	1.	2.	3.
	92	95	105
	95	86	105
	95	95	103
	95	99	113
	92	87	127
	93	89	101
	100	94	101
Mean	95	92	108

2-YEAR PERIOD, 1910–1921.

	1.	2.
	110	96
	116	99
	107	105
	115	97
	108	98
	109	82
Mean	111	96

The periods are much more marked in respect of the maximum years than of the minimum, the intervals at which maxima occur being 5, 5, 5, 4, 2, 3, 3, 3, 3, 3, 3, 4, 2, 2, 2, 2, 2. It is curious that the three stages correspond roughly with the three periods already mentioned,

ANNUAL GENERAL RAINFALL, British Isles, Expressed as per centage of Average 1881-1915.

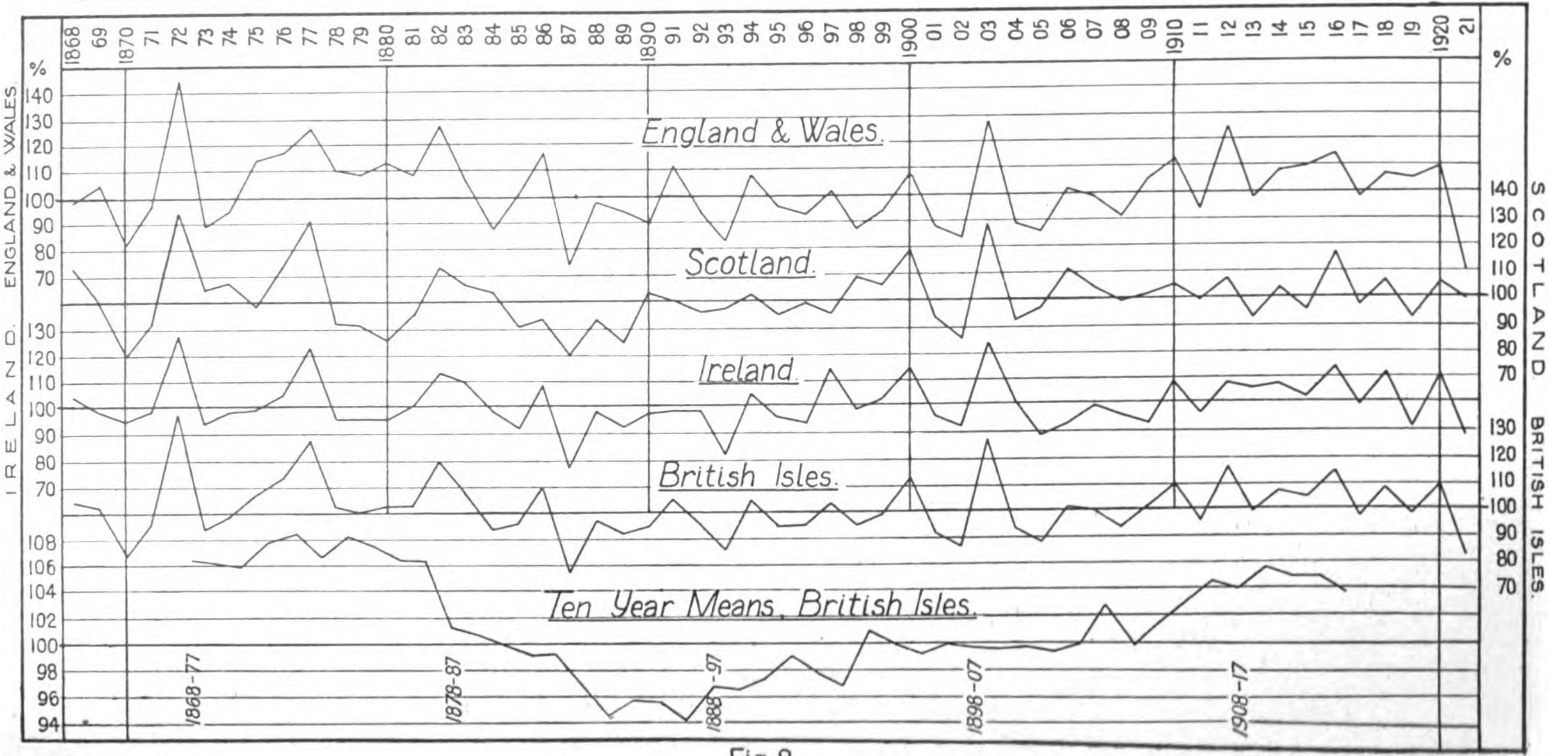


Fig. 8.

in which the preponderating types of distribution were marked by concentration of high rainfall in the east, west, and south, respectively. This may be a mere coincidence, but it suggests interesting speculations.

Dr. H. R. Mill and others[1] have previously called attention to the 3-year period in rainfall. Correlating each year in the whole series with the third following year, r is, however, only $+0{\cdot}40$ ($e = 0{\cdot}11$).

By smoothing the curves of general rainfall we get evidence of a long-period fluctuation with a maximum in the 'seventies, a minimum in the early 'nineties, and a second maximum culminating between 1912 and 1916. These features are common to all three countries, and no doubt represent the Brückner cycle. The smoothed curve for the British Isles is given at the bottom of Fig. 8.

RELATION TO MEAN ANNUAL PRESSURE.

The rainfall of the British Isles is so obviously carried by the prevailing South-Westerly wind-drift which skirts the north-western coasts of Europe, that it appeared reasonable to expect that a definite relation might be established between the variations of the two phenomena. The rainfall maps were first studied in relation to data of wind frequencies at Valencia, Stornoway, Aberdeen, and Kew. The method was not very successful, but there was a general suggestion that an excess of wind from any quarter was associated with an excess of rainfall on that side of the country.

The relation was much more clearly brought out by constructing maps showing the departure from the normal barometric pressure in western Europe during each year from 1868–1921.[2] The British Isles lie entirely within the belt of prevailing South-Westerlies, and the normal pressure distribution is represented by a series of nearly parallel isobars with a gradient of about 10 mb. between central France and Iceland. Over the British Isles proper the normal gradient is 5 mb. in 580 miles from Dungeness (1014·7 mb.) to Stornoway (1009·9 mb.). In this area the greatest departures from the normal régime during a calendar year do not amount in any case to an inversion, a common type of variation being a change in the steepness of the gradient.

The line of lowest pressure lies too far to the north to allow changes in its position, if any, to be followed from year to year. Similarly the belt of highest pressure to the south lies normally outside the map, but occasionally it appears to extend unusually far to the north.

In some years there is evidence of a local modification in the trend of the isobars in the immediate neighbourhood of the British Isles.

It would appear reasonable to adopt the hypothesis that the mean position of the circumpolar wind-drift shifts periodically from south to north.

The maps of annual pressure abnormality thus suggest that three main types of variation occur.

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[1] *British Rainfall*, 1908, p. [186]; *Q.J.R. Meteor. Soc.*, **39**, 1913, p. 29.

[2] The data used were chiefly drawn from Gorczynski, W., "Pression atmosphérique en Pologne et en Europe," Warsaw, 1917; Solar Physics Committee, "Monthly Mean Values of Barometric Pressure for 73 Stations over the Earth's Surface," London, 1908; Hann, J., "Vertheilung des Luftdruckes," Vienna, 1887; and from manuscript data in the possession of the Meteorological Office.

(i.) Variation in the position of the wind-drift. This is shown by excess or defect in the general pressure value for the year, not necessarily associated with any modification in the type of distribution, but not precluding it. (See Figs. 9 and 10.)

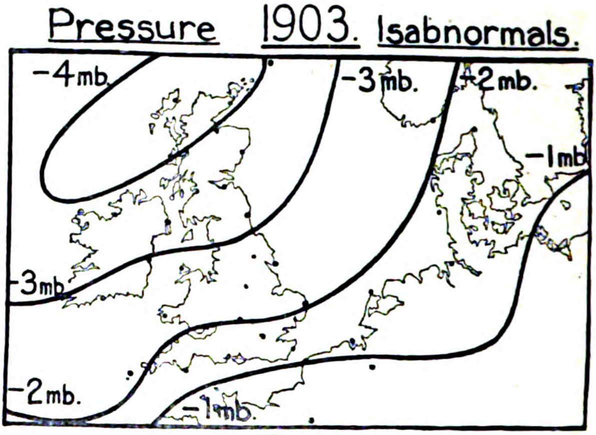

Fig. 9.

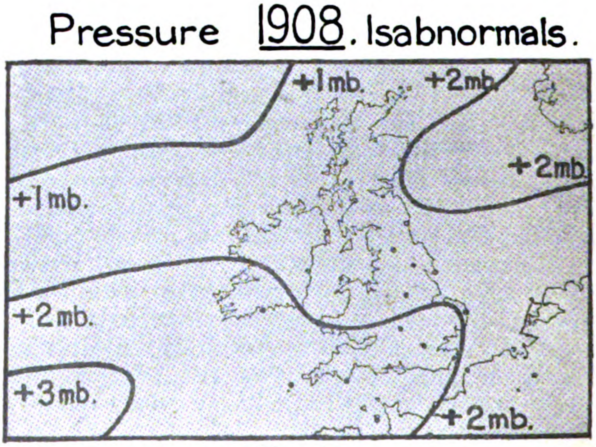

Fig. 10.

(ii.) Variation in the gradient. The characteristic of this type is a change in the relative pressure in the south to that in the north. (See Fig. 11.)

(iii.) Local irregularities. This class is less easy to define. It is best shown by changes in the relative pressure in the west to that in the east. The abnormality is occasionally sufficient to be indicated by enclosed areas of excess or defect on the isabnormal maps. (See Figs. 12 and 13.)

Variations of type (i.) were found to be most closely related to fluctuations in the amount of rainfall over the British Isles generally; variations of type (ii.) to changes in the geographical distribution of rainfall in relation to the average; and those of type (iii.) to both simultaneously. In considering the relation of each type to the rainfall, each pressure map in the series is considered from the point of view of its approximation to each type.

Tendency to Type (i.).—The first step was to compute from the pressure maps the general pressure over the area of the British Isles, irrespective of distribution, this being the best indication of the shifting northward or southward of the circumpolar wind-drift (see Appendix, Col. 10). Correlating the general pressure for each year with the general rainfall expressed as a percentage of the average gives $r = -0{\cdot}83$ $(e = 0{\cdot}04)$. Examination of the years in which the relationship was weakest showed no common features either in regard to pressure or rainfall distribution.

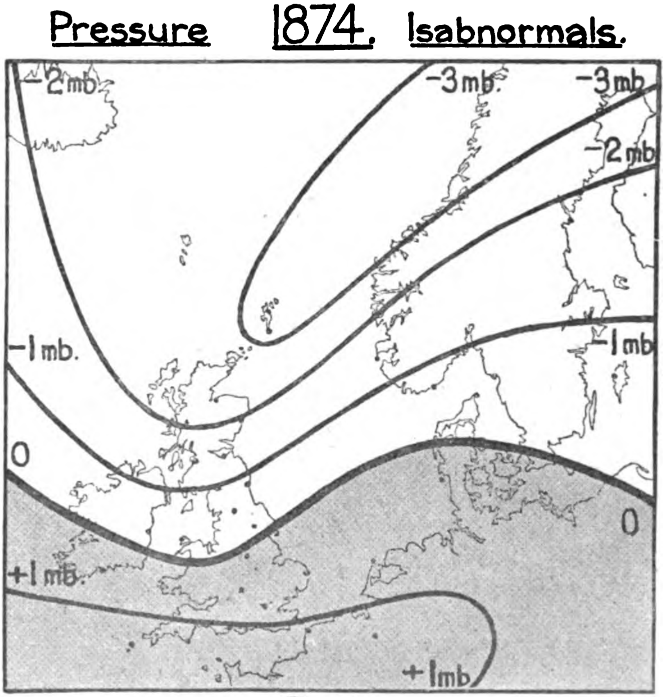

Fig. 11.

The periodicities observed in the rainfall curve were reproduced in the pressure curve, but less conspicuously, the mean abnormalities for the three periods mentioned earlier being:

5-Year Period, 1868–1882.

(Three repetitions.)

	1.	2.	3.	4.	5.
Mean pressure abnormality	−0·8	−0·2	+1·0	−1·0	−3·4 mb.

	3-YEAR PERIOD, 1889–1909. (Seven repetitions.)			2-YEAR PERIOD, 1910-1921. (Six repetitions.)	
	1.	2.	3.	1.	2.
Mean pressure abnormality	− 0·2	+ 0·8	− 0·6 mb.	− 1·3	+ 0·9 mb.

Tendency to Type (ii.).—For the purpose of reducing the variations in the pressure gradient to a curve the difference between the mean annual pressure at Dungeness and Stornoway was tabulated. The variations of this value from the average (see Appendix, Col. 11) may be regarded as the variations in the South-Westerly component of the wind-drift from year to year. Correlation with the general rainfall of the British Isles gives $r = +0{\cdot}26$ ($e = 0{\cdot}13$), showing that the fluctuations in the general rainfall do not correspond with those in the gradient. Mr. C. E. P. Brooks, dealing with the general trend of pressure and rainfall over the whole earth during the last half-century,[1] states that in that period the normal pressure gradient between Iceland and south-eastern England increased on the average 0·1 mb. per annum, whilst the rainfall decreased. He is of opinion that with increased gradient, depressions pass rapidly across the country and do not produce so much rainfall in the British Isles as slow-moving depressions.

1872. Pressure Isabnormals. 1887.

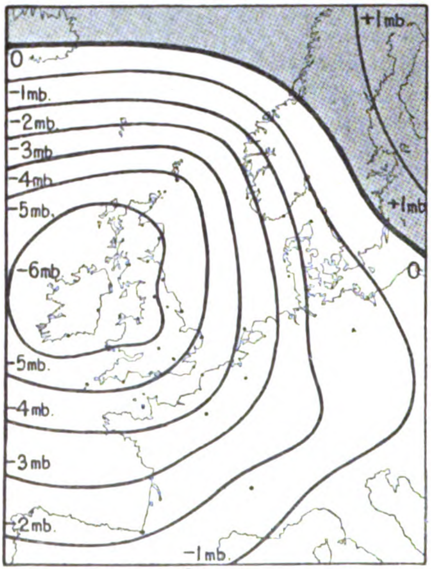

Fig 12

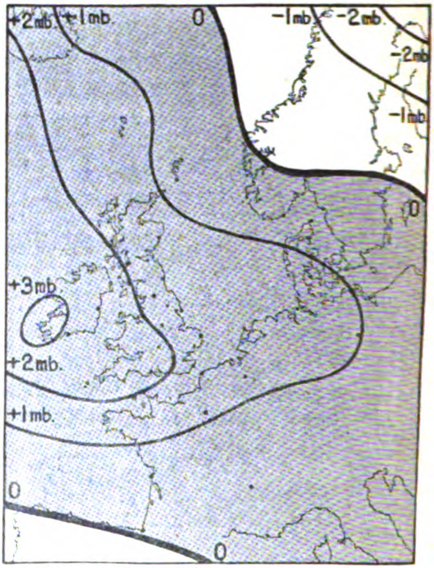

Fig 13

In order to relate the gradient abnormality approximately to the variations in type of rainfall distribution, group-values of rainfall as percentage of average were computed for (*a*) stations in the west of the British Isles, (*b*) east of British Isles, (*c*) south of British Isles, (*d*) north of British Isles (see Appendix, Cols. 5, 6, 7, 8). The excess of (*a*) over

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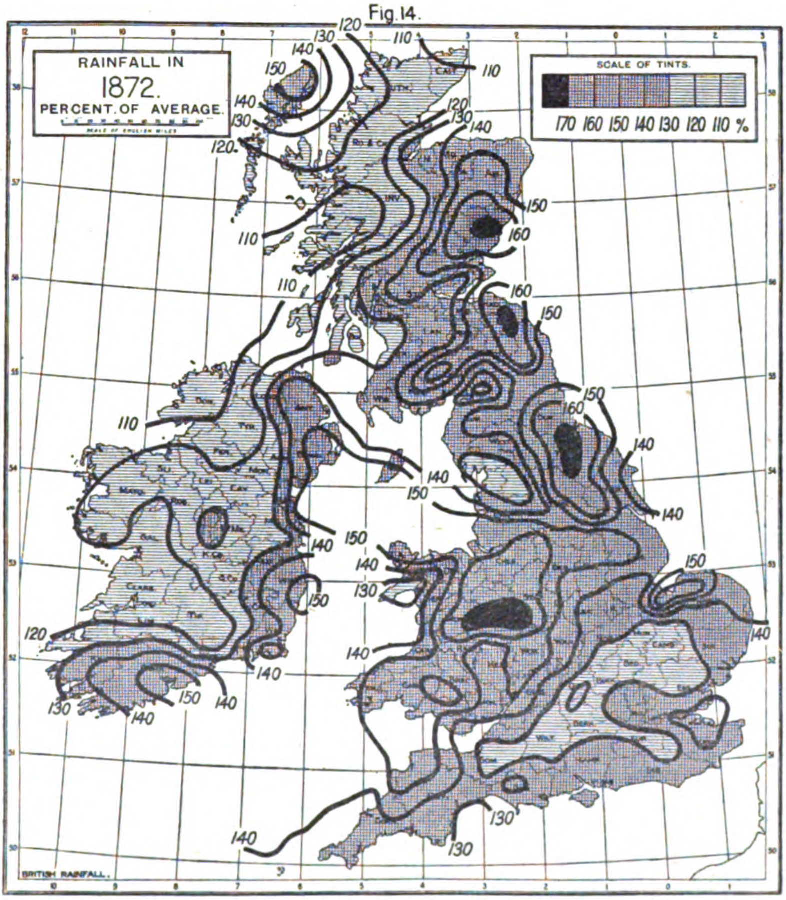
[1] "The secular variation of climate," *New York Geog. Rev.*, **11**, 1921, p. 127.

(*b*) was regarded as an index of a westerly type of distribution and *vice versa*. The excess of (*c*) over (*d*) was regarded as an index of concentration in the south and *vice versa*.

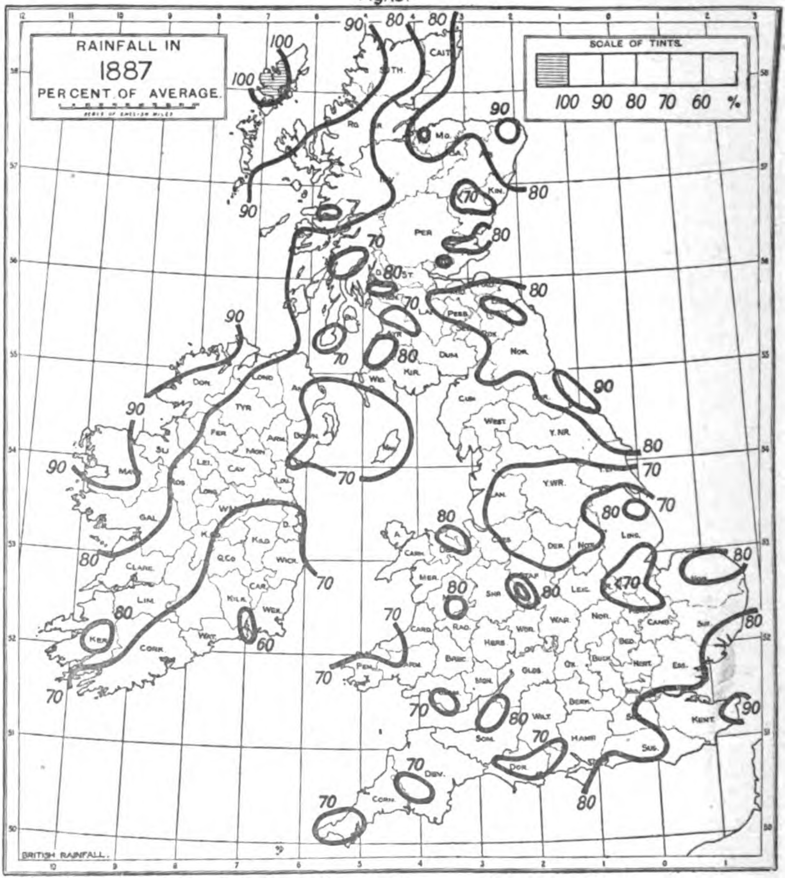
Correlating the South-Westerly component with $(a)-(b)$ we get $r=+0{\cdot}69$ $(e=0{\cdot}07)$, whilst the same series correlated with $(c)-(d)$ gives r only $-0{\cdot}26$ $(e=0{\cdot}13)$. It is notable that the largest South-Westerly components coincided with the years of most marked Westerly rainfall distribution, whilst the smallest South-Westerly components occurred in years with an almost inverse rainfall distribution. The years in which the relationship between the computed South-Westerly component and the rainfall distribution was weakest were those in which the pressure distribution was of type (iii.); in these years the local irregularities in the pressure made the difference between the mean values for Dungeness and Stornoway an imperfect index of the component. But for this fact r would undoubtedly have been higher than $+0{\cdot}69$.

Fig. 14.



Tendency to Type (iii.).—It is difficult to find a numerical expression which will adequately represent this type. A crude attempt was made to do so by taking the difference between the pressure at Valencia and North Shields, and regarding the variations of this value from its average as indicative of deflections from the normal trend of the isobars (see Appendix, Col. 12). Correlating this value for each year with the general rainfall gives $r = -0{\cdot}31$ ($e = 0{\cdot}12$); so that although the connection is weak, the tendency is for low pressure in the west to be more operative in increasing the general rainfall than low pressure in the east. It is also difficult to represent the characteristics of the associated rainfall distribution, since the most notable instances gave local patches of high or low rainfall which were not constant in position. Correlating the abnormalities in the pressure gradient between Valencia and North Shields with the rainfall values (*c*) – (*d*) and (*a*) – (*b*), above, gives *r* respectively $-0{\cdot}57$ ($e = 0{\cdot}09$) and $-0{\cdot}03$ ($e = 0{\cdot}14$). The former coefficient would probably be higher were it possible to find a more accurate expression for the variables.

Fig. 15.



These correlations, in conjunction with those found for type (ii.) above, appear to establish the fact that an abnormality in the pressure gradient operates at right angles to the line of the gradient, *i.e.* in the direction of wind-movement.

All years of rainfall greatly abnormal in amount, whether in excess or defect, occur with type (iii.) of pressure distribution, and in practically every case the isabnormals of pressure show enclosed areas of excess or defect. The best examples are 1872 (see Figs. 12 and 14), and 1887 (see Figs. 13 and 15).

In considering the generalizations which can be drawn from this investigation, and the significance of the correlation coefficients obtained, it is necessary to bear in mind that the conditions are not constant throughout any calendar year. The calendar year is, as a matter of fact, not a suitable unit for this work, since it is by no means impossible that the connection between pressure and rainfall is of a different nature in summer and winter.

The inquiry can, therefore, only be regarded as preliminary, and should, we think, be useful in indicating the lines along which a more detailed investigation might be prosecuted. Whilst it would clearly be impracticable to isolate and study, as separate units, all the periods during which the distribution types are pure, it appears to be desirable to continue the work by dividing the data into 6-monthly periods representing respectively the summer and winter half-years.

SUMMARY.

1. Maps expressing annual rainfall, 1868 to 1921, as a percentage of the average, fall roughly into three types, indicating respectively (i.) excess of orographical rain, (ii.) deficiency of orographical rain, (iii.) excess of cyclonic rain.

2. Nearly every year exhibits local areas of both excess and defect, the mean range of variation per annum being 35 per cent, with local extremes varying from + 80 per cent to − 59 per cent.

3. Distant stations show widely different fluctuations, but there is a general resemblance between group-values for the west and the east of the country. Local variations are of at least as great magnitude as general variations.

4. In the earlier years the maxima were generally in the east; in the middle of the period in the west; and in the later years in the south.

5. The general rainfall varied from 136 per cent of the average in 1872 to 77 per cent in 1887, the deviation exceeding 20 per cent in only 5 years, and averaging 8 per cent.

6. From 1868–1882 maxima occurred at intervals of 5 years; from 1889–1909 of 3 years, and from 1910 to 1921 of 2 years. There is evidence of a long-period fluctuation with two maxima about 40 years apart.

7. Annual pressure maps show three types of variation: (i.) due to shifting of the SW wind-drift to N or S; (ii.) changes in the gradient; (iii.) local deflections of the isobars. Type (i.) determines the amount of general rainfall; type (ii.) the distribution of rainfall; type (iii.) affects both variables, and includes all extremely dry or wet years.

	General Rainfall, British Isles—Differences from Normal, 1881–1915.							Prevailing Type of Rainfall Distribution (see p. 213).	Pressure—Differences from Normal.			
	British Isles.	Wettest Spot.	Driest Spot.	West (*a*).	East (*b*).	South (*c*).	North (*d*).		General Pressure (estimated from annual maps).	Gradient S-N (see p. 220).	Gradient W-E (see p. 222).	
Column 1.	2.	3.	4.	5.	6.	7.	8.	9.	10	11.	12.	Column 13.
	%	%	%	%	%	%	%		mb.	mb.	mb.	
1868	+4	+35	−20	+9	−4	+6	+5	w	−0·9	+2·6	+0·2	1868
1869	+2	+20	−20	+3	+2	−2	−4	c	+0·1	+0·3	+0·3	1869
1870	−16	+5	−35	−13	−16	−21	−19	I	+0·9	−1·1	−0·7	1870
1871	−4	+20	−30	−1	−7	−5	−10	I	0·0	−0·4	−1·3	1871
1872	+37	+75	+5	+37	+41	+32	+26	C	−5·7	+0·9	−1·0	1872
1873	−6	+20	−25	0	−7	−3	+1	I	−0·7	+0·7	+0·5	1873
1874	−1	+30	−35	+11	−9	−4	+12	W	−0·4	+2·8	+0·6	1874
1875	+7	+40	−20	+1	+12	+23	0	EC	+1·2	−1·1	−1·9	1875
1876	+13	+50	−20	+3	+19	+22	+7	EC	−2·3	−0·4	−1·4	1876
1877	+27	+55	+5	+27	+24	+26	+24	C	−2·9	+2·0	+0·2	1877
1878	+2	+40	−25	−5	+6	+10	−14	Ec	−0·7	−0·7	+0·2	1878
1879	0	+35	−25	−9	+3	+11	−14	Ec	−0·4	−0·2	−1·1	1879
1880	+2	+50	−30	−8	+13	+8	−13	C	+0·8	−0·5	−0·8	1880
1881	+3	+25	−20	−3	+6	+6	−6	e	−0·7	0·0	−1·4	1881
1882	+20	+50	−10	+17	+19	+25	+6	C	−1·6	+1·6	0·0	1882
1883	+8	+30	−10	+7	+10	+8	+1	I	−0·5	+1·0	+0·1	1883
1884	−6	+20	−25	+4	−16	−14	+2	W	+0·3	+2·0	−0·6	1884
1885	−4	+20	−25	−1	−5	+5	−7	c	−1·2	+0·1	−0·6	1885
1886	+10	+35	−15	+4	+6	+17	−5	c	−1·6	−0·9	−0·4	1886
1887	−23	0	−40	−21	−25	−25	−14	w	+2·0	−0·9	+0·9	1887
1888	−3	+15	−20	−6	−2	+4	−4	I	+0·3	−1·6	−0·3	1888
1889	−8	+25	−30	−14	−1	−8	−9	I	+0·7	−0·7	+1·0	1889
1890	−5	+15	−30	0	−2	−10	+6	I	0·0	+0·4	+0·3	1890
1891	+5	+30	−10	+3	+4	+9	−4	c	−0·4	+0·8	−0·2	1891
1892	−5	+20	−30	−10	+3	−17	−6	ec	−0·5	−0·6	+0·7	1892
1893	−14	+15	−35	−10	−13	−21	+2	w	+0·4	+0·7	+1·2	1893
1894	+5	+30	−10	+8	+4	+14	−4	I	−0·5	+1·2	−0·3	1894
1895	−5	+20	−25	−13	+3	−3	−2	E	−1·1	−1·8	−0·7	1895
1896	−5	+20	−25	−8	+2	−11	+7	I	+2·3	−0·7	+1·3	1896
1897	+3	+30	−25	+8	−6	+6	−10	w	−0·3	+0·6	−1·2	1897
1898	−5	+40	−30	+6	−11	−19	+12	W	+0·4	+1·6	+0·7	1898
1899	−1	+20	−20	+1	−5	−10	+4	I	+0·4	+0·9	−0·7	1899
1900	+13	+40	−10	+10	+16	+6	+14	e	−1·2	−0·3	+0·3	1900
1901	−8	+10	−30	−11	−5	−13	−7	I	+0·3	−1·3	+0·3	1901
1902	−13	+10	−30	−17	−10	−14	−9	I	+0·1	−0·3	−0·5	1902
1903	+27	+50	+10	+32	+20	+30	+25	C	−2·7	+2·8	−0·5	1903
1904	−7	+20	−25	0	−14	−3	−1	w	−0·4	+1·2	−0·5	1904
1905	−11	+10	−30	−12	−9	−11	+3	I	+0·7	+0·6	+0·3	1905
1906	+1	+30	−20	−1	+5	−4	+6	e	+0·1	+0·1	+1·5	1906
1907	0	+20	−15	−1	−2	0	+3	c	−0·5	+0·6	+0·2	1907
1908	−6	+10	−25	−3	−8	−12	+2	w	+1·9	−0·1	−0·5	1908
1909	+1	+25	−20	−7	+8	0	−1	E	0·0	−2·0	+0·1	1909
1910	+10	+30	−10	+10	+11	+16	+2	c	−2·1	−2·1	0·0	1910
1911	−4	+15	−25	+2	−4	−5	−2	w	+1·5	−1·0	−0·9	1911
1912	+16	+45	−5	+15	+16	+24	+9	C	−1·9	−0·7	−1·3	1912
1913	−1	+20	−25	+4	−9	−1	−8	w	+0·1	+0·5	−1·0	1913
1914	+7	+25	−10	+11	+3	+15	+1	W	−1·1	+1·3	−0·3	1914
1915	+5	+35	−30	−4	+7	+18	−9	Ce	−0·9	−2·1	−0·8	1915
1916	+15	+40	−5	+12	+20	+17	+6	Ce	−2·7	0·0	+1·0	1916
1917	−3	+20	−25	−7	+2	−3	+3	I	+1·2	−1·3	+1·2	1917
1918	+8	+30	−15	+13	+5	+5	+9	W	+0·4	+1·1	+0·3	1918
1919	−2	+20	−25	−10	+5	+3	+1	E	−0·1	−1·4	+1·6	1919
1920	+9	+30	−20	+10	+3	+1	+5	W	−0·3	+2·2	−0·9	1920
1921	−18	+30	−50	−6	−24	−38	−4	W	+3·9	+1·4	+0·6	1921
Mean	+1·4	+28	−21	+1·2	+1·6	+1·7	+0·3	...	−·30	+0·1	−0·1	Mean

ADDENDUM.

In order to amplify the section dealing with the Geographical Distribution of Variations, Mr. Glasspoole referred to a map he had recently constructed to show the comparison of the fluctuations of annual rainfall for the 35 years 1881–1915 over the British Isles in relation to that at a standard station, Radcliffe Observatory, Oxford. The method adopted was to evaluate the correlation coefficients, the annual rainfall at some 50 stations in the British Isles being correlated with that at Oxford.

If there is no relationship between the values of the annual rainfall for two stations the correlation coefficient should be 0, while the greater the relationship the more nearly will the value approach unity.

Over a considerable area stretching from Cardiff practically to London the correlation coefficient was as high as 0·90. With Magdalen College, Oxford, a few miles away, it was as high as 0·96. The value of the correlation coefficient diminished with increasing distance, but more rapidly to the north than to the west. The value was as high as 0·70 only to the south of a line from Aberystwyth to York and then to Margate. Values of less than 0·30 were confined to the northern half of Scotland, and further northward the value fell off rapidly to 0·00 along the north-west coast, and over the Hebrides. At Stornoway a value of − 0·01 was obtained. The centres of the land masses showed relatively higher values than along the coast. This result was doubtless connected with the high value of the mean deviation of annual rainfall over these areas[1] and the influence of convection on the rainfall.

While the fluctuations of annual rainfall 1881-1915, in practically all parts of the British Isles, bear a distant relationship to the fluctuations at Oxford, as if they are all determined in the main by some common factor, stations to the north-west of the Caledonian Canal show no such relationships. During these years the influences which affected the rainfall fluctuations in the extreme north-west of the British Isles were presumably of a different nature from those controlling the fall over the country generally.

DISCUSSION.

Dr. H. R. Mill writes :—I am disappointed at my inability to be present at the reading of this paper, as I should have liked personally to congratulate my old colleagues on their effort to correlate the distribution of rainfall and atmospheric pressure over the British Isles. The ambition to undertake such a piece of work was before me for many years, and when in 1904 I introduced into *British Rainfall* maps which aimed at cartometric rather than diagrammatic value it was with the definite hope that they would ultimately be put to such a use.

I fully appreciate the difficulties with which the authors have been faced, and I agree that a certain lack of definiteness in the result is largely due to the calendar year being an unsatisfactory unit with which to deal ; but it is the only practicable time-grouping for a study based on mean values for the whole area of the country.

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[1] See *British Rainfall*, 1921, p. 293.

In classifying the types of rainfall distribution I agree fully with the statement that one type rarely occurs alone, and indeed I am inclined to stress, even more strongly than the authors do, that in a year's rainfall as represented on a map the predominance of one type over the others is difficult to determine. The "normal" orographical distribution of rainfall depends of course not only on the orography of the country but on the constancy of the prevailing wind. When Easterly or Southerly wind prevails for a substantial period the orographical distribution is quite different from that produced by a South-westerly wind, and in years of exceptionally frequent East wind, for example, purely orographical rains would show a distribution very different from the normal. I remember on one occasion constructing a number of consecutive monthly rainfall maps of the Aberdeenshire district and finding a very clear orographical distribution for months in which East winds predominated, contrasting sharply with the orographical distribution in the more frequent months which showed a great excess of South-westerly winds.

It seems to me that if means for so laborious a research are ever available there would be hope of reaching definite conclusions in a study of the rainfall of the country from maps of rainfall and pressure based on groups of consecutive months in which the average wind direction was similar, although the group with prevailing East wind contained a smaller number of months than the group containing West wind. The object should be to get groups each concentrating one type of distribution ; in consecutive groups of twelve or even six months the various types neutralize each other to some extent and the resultant is a blurred image. This holds good for periods in which orographical rainfall prevails, even although great convectional or cyclonic rains are poorly represented.

The treatment of the fluctuations of general rainfall from year to year interests me greatly. The trouble in dealing with this fascinating subject in *British Rainfall* used to be the want of a standard of reference to which all the years of a long period could be equally referred, and this difficulty the authors of the present paper have overcome. The three-year period of general rainfall which seemed so attractive as a possible guide to long-period forecasts appears more clearly marked than ever, the later two-year period is equally well marked and an earlier five-year period indicated. As a personal matter of no importance I might remind readers not acquainted with the last twenty volumes of *British Rainfall*[1] that I did not at any time view the three-year period as permanent. As early as 1906 I said :

"As a sequence of one wet and two dry years does not seem to have held good before 1891 it is only reasonable to expect that it will cease to hold good some time in the future," and in due course the change came.

I think it is possible that a study of the course taken by the tracks of depressions in different years might throw light on some aspects of the relation of areas of deficient and excessive rainfall which the more general relations of mean pressure and rainfall fail to reach ; but that lies outside the scope of the present paper as an inducement to future research.

The only justification for a man of science to struggle with the vast mass of intrinsically uninteresting detail of rainfall observation and recording is to find a clue to the succession of phenomena which brings them into relation with the wider aspects of atmospheric physics and the measure of constraint imposed by geographical control.

This paper by friends who worked with me for many years and are now pushing into regions I longed to explore helps to diminish the disappointment I can never cease to feel at having to leave the work just when the methods of effective study had begun to show the promise of results.

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[1] *British Rainfall*, 1905, p. [161].

Mr. H. MELLISH, in congratulating the authors of the paper, said it was a very ample record of the boiling down of results in the way we have always associated with the British Rainfall Organization. The number of observations must have added considerably to the work of the paper, which had been presented in a clear and interesting manner and lucidly illustrated by the diagrams. With regard to these diagrams he felt that they should be available to the public. A description of them was included in the paper, but the maps told the story of the fluctuations of rainfall from 1868 onwards much better than the paper could possibly do without them. We had a set of 54 years of percentage maps and a longer series of 60 years of actual rainfall maps. Some of these percentage maps had been printed in *British Rainfall*, but the normals in use have varied and there has never been a homogeneous series like this. It would be of value if some means could be found to reproduce these maps and make them available. This would do a great deal to facilitate the study of rainfall and the questions involved.

Mr. J. E. CLARK said the first point which struck him—and his thoughts naturally turned to phenological work—was whether it would be possible to follow up this study of the annual variations by monthly or half-yearly reports. What they wanted for phenological work was values from December to July, and to be able to compare these months with the records from 1891 onwards would be of very great interest. Of course the monthly values also would have a considerable value. To illustrate this, at York the enormous excess in the 'seventies was accounted for by the heavy September rainfall, which in that decade ranges first in the wet months though otherwise fourth or fifth. To see which were the wettest months of the 'seventies and to see how that would account for the heavy rainfall of 1872, for instance, would be of decided interest; and if September were taken out, to see what difference it would make in that decade compared with the other decades [1831 to 1920] with September also taken out.

Mr. R. H. HOOKER said they had to congratulate the two authors on their paper. They always looked for something new from Mr. Salter, and the paper was a good example of work done without the employment of high mathematics, and showed what a great deal there was to be done of value in a comparatively simple manner. If they had a mass of facts and wanted to represent them in a condensed form, two main things were required: a single figure representative of the whole, and the amount of variation from such an average figure. The former was very generally calculated, but the latter was very often neglected, and the great merit of this paper was that an attempt was made to remedy a serious lacuna in the rainfall statistics of the country. Generally speaking, a good idea of the variability was given by the standard deviation, and he was a little sorry that this had not been given here. One remark that had attracted his attention was the expression, "Of the whole series of 54 years none shows a distribution closely resembling the average." This was often a very interesting feature in averages: there were many classes of observations in which the average was not in the least representative of the whole mass of data: this applied especially when the distribution of the observations was very asymmetrical. The case reminded him of a well-known statement by the statistician Quételet to the effect that "the mean man does not exist." By this was meant that no man had ever been found to exist all of whose measurements were exactly equal to the average. The fact that the distribution never closely resembled the average raised the interesting question as to what was the commonest type of distribution and in what respects it varied; but it was difficult to see how this could be exhibited in less than three dimensions at least. If there were any blemish in the paper, he thought there was a little difficulty in realizing precisely what was meant in each case by such words as average, percentage, etc. An "average" rainfall might mean the average in any given year of all stations, or it might mean the average of a series of years, and he thought the authors were not always quite clear as to which was meant in every case. On the question of averages, again, he was rather sorry that in the table in the Appendix only 35 years had been used instead of the whole 54. The effect was to produce apparent anomaly; the mean of the deviation in column 1, for instance, appears as + 1·4. Of course the sum of the deviations from the mean in any series should be zero, and the figures + 1·4, etc., really seem rather large. They meant that the years preceding 1881 were wet. Such a result indicated a measure of the error introduced by an average of 35 years instead of 54, and showed that the 35 years were not sufficient to give the true representative mean rainfall.

Mr. C. E. P. **Brooks** said that he thought the paper was a great advance towards the interpretation of rainfall statistics, and he hoped the authors would be able to extend it to the monthly rainfall before very long. For many purposes—including holidays—the month was a much more practical unit than the year. For a large part of the period covered monthly maps of the pressure deviations over the northern hemisphere had already been drawn, and from 1910 onwards there were the *Réseau Mondial* maps. There was one other point to which he wished to refer; it concerned the periodicity of rainfall. The periodicities found—five years from 1868 to 1882, three years from 1889 to 1909, and two years from 1910 to 1921—represented a single periodicity which gradually decreased in length during the time covered by the observations. If the periodicities were represented on a graph by horizontal lines with ordinates of 5, 3 and 2 on a time scale from 1868 to 1921, a smooth curve could be drawn through the centres of these three lines. Some time ago he had had occasion to investigate the periodicity of solar protuberances from 1875 to 1914, and had also found that it decreased in length during those years. The periods found were 3·7 years from 1875 to 1892, about 3·1 years from 1892 to 1900, and 2·5 years from 1904 to 1914. If these were plotted on the same graph as the rainfall periodicities, the same smooth curve fitted them almost exactly. He thought that if the solar protuberances had been available for the same period as the rainfall, the same periodicities would have been found; but as the period was shorter at either end, the periodicities found were intermediate. He considered that there must be some relationship between the number of solar protuberances and the mean rainfall of the British Isles.

Mr. L. C. W. **Bonacina** said there was a feature in Dr. Mill's remarks which called for comment. That was the suggestion of a marked dislocation in the distribution of orographical rainfall during periods of persistent East winds. It would, he thought, be allowed now that in the bulk of the cases of rainfall with East wind the moisture is mainly drawn from the Westerly Atlantic current, the rain falling through the relatively dry Easterly wind. It was remarkable that so pronounced a dislocation should be found, and the only solution he could think of was that the excess of rain in the hills, whether with East or West winds, is to a considerable extent due to the predominance of hill-fog, and that the large excess of moisture which rain-gauges collect in such localities is largely deposited by hill-fog and drizzle. If a relatively dry Easterly current were forced upward by high ground there would be cases where condensation in it could reach the point of mist-formation without real rain, though real heavy rain produced by a warm Atlantic current above the Easterly current might be falling through the latter, in accordance with Bjerknes's representation of the structure of barometric depressions. He was glad of what had been pointed out about averages. An average was a convenient standard of reference; but practically all weather consisted in varying degrees of a succession of what might be termed "normal abnormalities."

Mr. J. GLASSPOOLE in reply said that he felt they were indebted to the speakers for their helpful criticisms, to which attention would be paid in further investigations. The paper was a preliminary one, and much work remained to be done. With regard to Mr. Clark's remarks about the wet Septembers in the early 'seventies, he thought the most interesting feature of the rainfall of September was the large value of the mean fluctuations of the rainfall of September, the mean duration of monthly rainfall for the period 1881–1915 being largest in February and September.

Replying to Mr. Hooker's remarks, he said that a map showing the distribution of the standard deviation of annual rainfall for the 35 years, 1881–1915, had been prepared, and a map of the mean deviation for the 35 years published in *British Rainfall*, 1921. They had endeavoured to keep the use of the word "average" to apply to the period 1881–1915, whether for an individual station or for the British Isles as a whole. To have used an average for the whole period throughout the paper would doubtless have been simpler, but would have meant so much additional labour that the paper could not have been finished for some years.

He thought that maps of the monthly rainfall as a percentage of the average would be available for certain months, but that initially fewer stations would be used. He was particularly interested in Mr. Brooks's remarks on the relation between the periodicities of annual rainfall of the British Isles and of solar protuberances.

Award of the Johnson Memorial Prize to Mr. G. M. B. Dobson.

We have pleasure in announcing that Mr. G. M. B. Dobson has been awarded the Johnson Memorial Prize in 1923 for his paper on "Measurements of the Sun's ultra-voilet Radiation and its Absorption in the Earth's Atmosphere."

Manuel Johnson, after whom the prize is named, was Radcliffe Observer from 1839 to 1859, and did a great work in developing the Observatory. The prize was founded in memory of him by his friends and admirers in 1862. It consists of a gold medal and a sum of money, and is offered for competition once in every four years for an essay to be written on an astronomical or meteorological subject by any member of the University of Oxford.

The prize was offered first in 1867, but on six occasions no award was made owing to lack of suitable candidates, and Mr. Dobson is only the eighth holder. Mr. Dobson's paper is published in the *Proceedings* of the Royal Society, Vol. 104 (ser. A), 1923, pp. 252-271.

Geophysical Papers of the Royal Astronomical Society.

In the *Quarterly Journal* for April 1922 it was announced that the issue of a series of occasional Geophysical Supplements to the *Monthly Notices* of the Royal Astronomical Society was being commenced. The first of these supplements appeared in March of that year, and up to the present three numbers have been issued, containing papers on Seismology, Wireless Time Signals, Terrestrial Magnetism, etc.

Fellows of this Society are reminded that they may obtain the supplements by applying to the Assistant Secretary, Royal Astronomical Society, Burlington House, London, W.1, at a price just sufficient to cover the cost of publication. A deposit of 10/- should accompany the application.

Meteorological Observations at El Peru, Venezuela.

Since 1910 observations have been taken regularly, at the instance of Mr. C. B. V. Storey, at the works of the Goldfields of the Venezuela Company, situated at El Peru, in the Orinoco Valley. Observations from this country are so rare that the accompanying table of averages and extremes based on about ten years' records should be of considerable interest. The climate is not extreme; the mean annual temperature of 77°·6 F. at a height of about 720 feet (determined from the barometric observations) corresponds with a sea-level reading of 80° F., which is normal for the tropics. The annual variation is small, but the daily range is as high as 16° F.; the maximum recorded temperature is only 95° F. The average annual rainfall is 1416 mm. (55·7 inches), the chief rainy season being from May to September, with a lesser rainy season in December and January. The fall of 272 mm. (10·7 inches) in August 1921 was exceptional; as a rule the rain falls in small amounts distributed over a number of days. The high relative humidity is due to the early hour of observation, usually about 7.30. Unfortunately the observer was not always able to observe at that hour, and many observations of pressure and humidity have had to be omitted because they were made later in the day.

C. E. P. B.

METEOROLOGICAL TABLE FOR EL PERÚ, VENEZUELA.

Lat. 7° 30′ N. Long. 62° 0′ W. Height above M.S.L. 720 feet.

MONTH.	PRESSURE AT M.S.L.	TEMPERATURE.								Relative Humidity.‡	Cloud Amount. Scale 0–10.‖	RAINFALL.		
	Daily Mean.‡	Daily Mean.†	Mean Daily Extremes.		Mean Monthly Extremes.		Absolute Extremes.				Amount.	Max. in 24 hrs.	Days of Precipitation.§
			Max.	Min.	Max.	Min.	Max.	Min.					
	mb.	° F.	° F.	° F.	° F.	° F.	° F.	° F.	%		mm.	mm.	
January .	1011·0	75·5	83·1	68·0	87	64	89	59	92	5·6	100	36	16
February .	1011·3	76·2	84·1	68·2	88	65	90	62	91	6·3	75	57	11
March .	1011·3	77·1	85·7	68·5	90	64	91	62	89	5·3	55	51	10
April .	1010·9	78·9	87·7	70·0	91	67	93	63	87	5·5	78	62	9
May .	1010·8	79·1	87·5	70·7	91	68	93	65	88	5·9	150	83	16
June .	1011·4	77·8	85·5	70·1	89	67	94	61	92	6·9	199	65	21
July .	1012·1	77·5	85·4	69·6	88	67	91	62	92	6·0	178	111	21
August .	1011·1	78·2	86·5	69·9	89	66	93	61	89	5·5	181	272	14
September .	1010·4	78·7	87·3	70·1	90	68	92	65	87	4·9	115	87	8
October .	1009·5	78·3	86·5	70·1	90	67	95	62	89	6·0	89	79	6
November .	1009·1	77·7	85·6	69·8	89	67	92	62	92	6·4	90	96	10
December .	1009·8	76·4	83·3	69·5	87	66	89	64	93	...	106	33	17
Year . .	1010·7	77·6	85·7	69·5	92*	62*	95	59	90	...	1416	272	159
No. of Years of Observation	10–12	...	8–10	9–11	8–10	8–11	8–10	8–11	10–12	1–2	11–12	10–12	

* Mean of highest (or lowest) each year. † ½ (Max.+Min.). ‡ Mean of observations at 7½ h. approx.

§ 0·3 mm. or more. ‖ Mean of observations at 7, 14, 21 h.

(*A.*) AN IMPROVED ACTINOGRAPH.

By ARTHUR W. CLAYDEN, M.A., F.R.Met.Soc.

[Received March 6—Read May 16, 1923.]

In April 1911 I described to the Society an instrument, which I called an Actinograph, for recording and observing the daily changes in radiation.

The essential parts of that instrument were two bimetallic coils mounted about a common axis in such a manner that the recording pen made no movement for any change of temperature which affected both coils equally, but responded at once to any difference of temperature between them. One coil was blackened and exposed to the sun and sky, while the other was bright and was also shaded by a bright tin cover. Full details of the construction were given in the original paper.[1]

This instrument was continuously at work in my garden until a few months ago, when the glass shade came to grief, and in those eleven years its working was quite satisfactory. With a little experience it is easy to read the meaning of the record, but there are in it some peculiar features which are not easily explained; and when I came to endeavour to interpret the tracing in a statistical way I was confronted with serious difficulties.

In the first place, the movements of the pen in dull wintry weather were too small to give reliable comparisons, and secondly, I was uncertain how far the effect was modified by the diurnal and annual variations in the angle at which the sun's rays fell on the coils. Moreover, the inevitable glass shade introduced another factor of unknown value. Hence I was led to attempt to find means whereby these difficulties could be overcome, or at least minimized, with the result of the construction of the improved form now to be described.

In this improved shape the diameter of the recording drum is increased to 6 inches, and the length of each coil to 7½ turns. A much more open record is thus obtained, and there have been very few days which have given no measurable movement. The axis of the earlier machine was horizontal, east and west, giving a daily wide change in the obliquity of the incident rays. In the improved form the axis points to the pole, so that there is no diurnal variation and very small annual variation in the angle of incidence.

With regard to the glass shade, one as nearly hemispherical as possible was chosen, and the blackened coil was placed approximately at the centre of curvature. Under these circumstances, whatever effect the shade may produce, that effect must always be the same. Any effect in lessening the radiation falling on the coil will be proportional to the total radiation received, and the records written on the drum on any two different days must bear the same relation to each other as would have been the case had no shade been necessary. The second, or bright coil, is not exposed to the sky, but is in the shade of the stand which carries the instrument (see Fig. 1). It thus has the temperature of the air, while the blackened coil has the additional temperature due to the radiation received.

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[1] *Q.J.R. Meteor. Soc.*, 37, 1911, p. 163.

Generally speaking, the pen rises in the morning, and descends again to the neutral line in the evening. It has only shown a negative trace below the neutral line on a few occasions, when the shade was suddenly chilled by a cold shower. Such negative traces were always brief.

TABLE I., SHOWING THE AVERAGE FOR EACH MONTH FROM MARCH 1914 TO MAY 1919.

YEARS.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1914	...	...	73	155	102	142	116	113	107	53	32	23
1915	33	53	79	111	103	132	109	106	91	36	24	19
1916	27	38	60	125	111	118	119	104	81	46	34	23
1917	16	32	57	108	123	121	128	97	84	57	25	24
1918	24	41	58	106	143	138	102	118	94	47	32	24
1919	28	39	77	104	118	...	...	...	...	...	...	...
Average	25·6	40·6	67·3	118·2	116·5	130·2	114·8	107·6	91·4	47·8	29·4	22·6

The unit adopted is arbitrary, so that the figures are only comparative and cannot be translated into calories per minute without calibration of the instrument *with its shade.* There is no Campbell-Stokes record near enough to be worth comparison.

As the axis of the coils is inclined to the horizon its movements are transmitted to the pen by means of a fine chain passing over a free-running pulley. The whole instrument works very satisfactorily. It had been in regular use for about eight years when a sudden violent squall tore off the shade and broke it up. As this occurred at a time when a new shade was not to be obtained, the record was ended for a while.

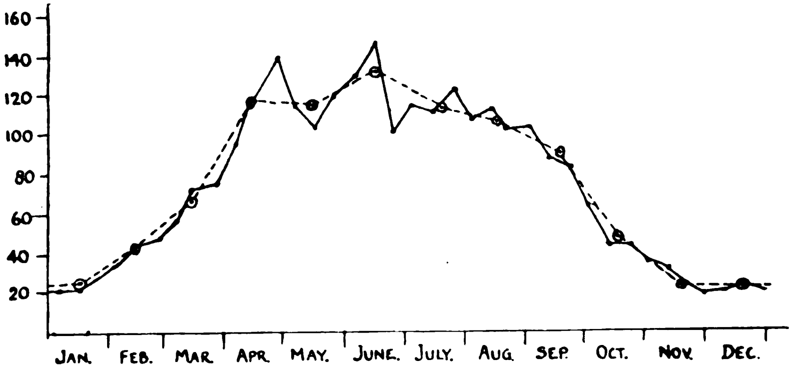

FIG. 2.—Readings of actinograph records for 5 years, March 1914 to May 1919.

The continuous line gives 10-day averages plotted every 5th day.
The dotted line gives monthly averages plotted on the middle of each month.

The instrument is again at work, but the shade is of a different make, so the records are not strictly comparable. I had, however, five years of observations complete, so it seemed worth while to examine them in some detail.

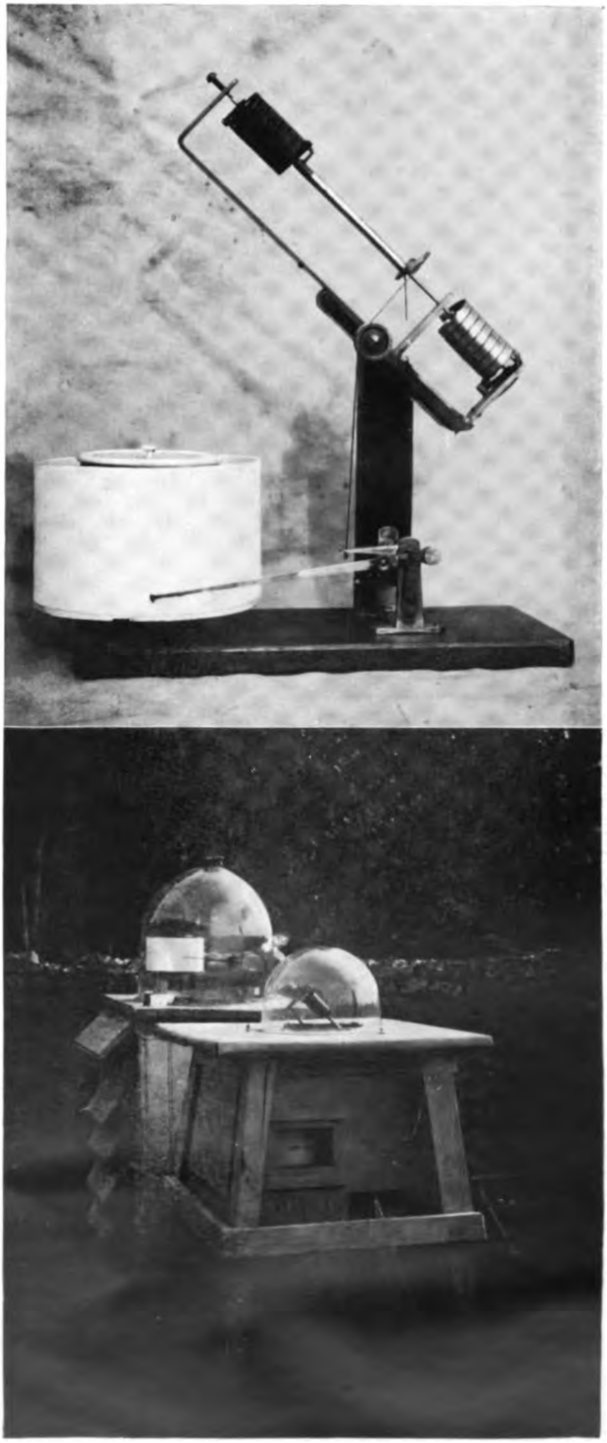

Fig. 1.—Above, the instrument; below the instrument in position.

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In order to translate the curves into figures the areas above the neutral line were measured with a planimeter graduated to hundredths of a square inch, and the numbers were plotted on millimetre paper. Table I. gives the monthly figures from March 1914 to May 1919. I have plotted two curves based upon monthly averages and 10-day averages (Fig. 2), both of which show that the increase in radiation in spring is much more rapid than the decrease in autumn. The cold snap of May is also plainly indicated. The instrument is illustrated in Fig. 1, (*a*) showing the complete instrument, and (*b*) the instrument in position.

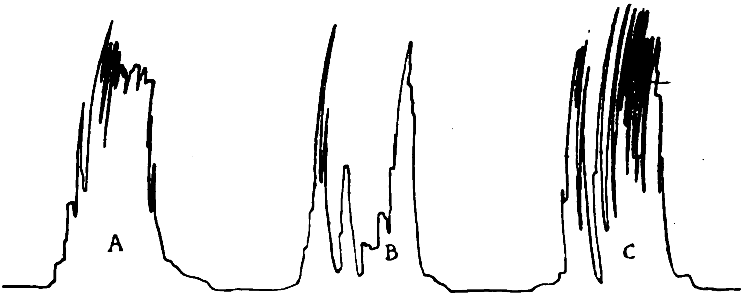

FIG. 3.—Actinograph record.

Fig. 3 represents three days' record in June :—

A. Small detached cumulus in the morning; cirrus bands in the afternoon; cirro-stratus of growing density in the evening.

B. Bright morning and evening, with heavy clouds and rain in the middle of the day.

C. Large cumulus with bright intervals; a shower at 10 o'clock.

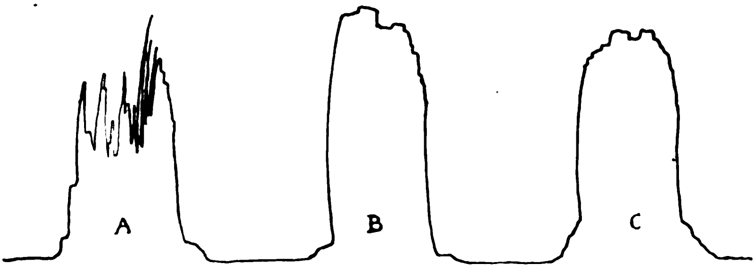

FIG. 4.—Actinograph record.

Fig. 4 represents three further days' record in June :—

A. Small cumulus with bright intervals increasing towards evening.

B. Almost cloudless day, only a few thin cirrus clouds.

C. Similar, but the cirrus rather more abundant.

These examples show the use of the instrument as an adjunct to the study of clouds, and as giving a record of weather changes.

(*B.*) NOTE ON THE INFLUENCE OF A GLASS SHADE.

By ARTHUR W. CLAYDEN, M.A., F.R.Met.Soc.

As the instrument described in the previous paper requires the protection of a glass shade, a brief note on the influence of such a cover seems desirable.

When radiation falls on glass, part is absorbed, part reflected, and the rest transmitted. The fraction absorbed depends upon the kind of glass, its thickness, and the wave-length of the radiation, but with sunlight as the source and a thin colourless glass the fraction is so small as to be almost negligible. The fraction reflected depends on the polish of the surface, the kind of glass, and the angle of incidence. Thus with a clean surface Barker[1] states that crown glass reflects at perpendicular incidence $\frac{1}{23}$, and flint glass $\frac{1}{15}$. These measurements I have verified by experiment.

I have also verified the same author's statement as to the effect of varying the angle of incidence, both by experiment and by calculation from Fresnel's formula. It thus appears that for angles of incidence up to 30° the reflected fraction is small, but it increases more rapidly than the angle, so that at 60° only about two-thirds is transmitted, while at glancing incidence by far the larger part is reflected.

It thus appears that the glass should be thin, always of the same kind, and that the radiation should always be incident at the same angle and as nearly as possible perpendicularly. This can be done by using a spherical or hemispherical shade, and placing the instrument at the centre of the sphere.

The radiation transmitted warms the objects within the shade, causing them to radiate wave-lengths which are easily absorbed by glass. This and convected heat together warm the internal face of the shade, setting up a thermal gradient in the glass whereby the energy escapes to the outer face by conduction, to be lost by convection and radiation. At first the influx is the greater, and the temperature rises until the rate of loss equals the rate of gain, and a steady state is reached. If now the influx is lessened the escape goes on until again a balance is established. Variations in the incident radiation will therefore be faithfully recorded with only a small time lag. To convert the comparative results into absolute measures the fractions lost by absorption and reflection must be determined.

DISCUSSION.

The President (Dr. C. Chree) said he thought a comparatively cheap instrument would be useful provided it gave consistent numerical results, even if they were only relative ones. It would, he thought, be desirable to compare the apparatus with one of a type giving absolute values of solar radiation.

Mr. M. A. Giblett asked what the instrument really measured. It recorded the difference between the temperature assumed by the exposed black coil and the temperature of the air surrounding the bright coil, but this would, he thought, be difficult to express in terms of radiation.

Mr. L. C. W. Bonacina said Mr. Giblett's point had not occurred to him, but he thought Mr. Clayden's apparatus from a comparative point of view seemed to have useful possibilities. As our bodies are not horizontal surfaces

[1] Barker, of Philadelphia. *Text-book of Physics* (Macmillan & Co.).

he thought Mr. Clayden was wise to eliminate diurnal and annual variations in the angle of incidence. Even then it does not eliminate the varying thickness of the atmosphere, so that the instrument is not exclusively a meteorological instrument, that is to say, one measuring the variations of radiation so far as they depend upon the cloudiness and transparency of the atmosphere. With regard to the curve shown of the monthly variation there is an anomaly. There is a high peak in April with which the dip in May is associated. It looked as though these five years were unusually sunny in April. The average amount of sunshine, both for astronomical and meteorological reasons, is shown by the long-period records to be less in April than in any of the four summer months which follow. The Callendar records at South Kensington (see *Met. Mag.*, March 1923) for practically the same period as that given by Mr. Clayden show an anomaly in May quite in the opposite direction, inasmuch as the amount of energy received in that month was greater than should be the case according to the astronomical position of the month. Therefore, Mr. Clayden's anomaly was chiefly due to a very local excess of sunshine in April in those five years in whatever part of the country the observations were taken.

Dr. G. C. **Simpson** asked for information regarding what it was supposed the instrument was measuring. It could not be solar radiation, for heat was received from the glass cover, as was shown by the fact that the instrument never recorded loss of heat even on clear nights. The Meteorological Office is at present interested in measurements of radiation in consequence of recent medical research on the effect of radiation in disease, and a simple instrument giving records which could be interpreted in physical quantities would be valuable.

Mr. A. W. **Clayden**, in answer to Dr. Simpson's criticism as to what the instrument was measuring, said that the records it gave were records of the kind of weather experienced, and with the application of the time scale one could get the exact time at which any event happened. He instanced a period of three days of bright cloudless sky. From another day's trace he knew there was blue sky with a few clouds in the morning, that it was overcast in the middle of the day, and with the time scale he could see the exact duration of cloudiness. The chief use to which he put the instrument was as a qualitative measure of the weather changes rather than for statistical purposes to measure the observed radiating power of the sun. The bright coil is in the shadow of the stand and presumably is at the temperature of the air, and the instrument measured the difference in temperature between the air and the black coil exposed to the full radiation of the sun. That is proportional to the rate of influx of energy from the sun, and therefore it will be proportional to the power of the radiation. Even when not exposed to the direct rays of the sun on a dull day there is a record, but the area recorded is small. He had used the instrument rather as a means of recording the weather than as a means of measuring the intensity of the solar radiation, because it would be necessary to compare the instrument with some standard apparatus in order to be able to give the radiation in calories per hour or day. He had not made any allowance for the expansion of the chain, but it was trifling. With regard to the excess in April, he merely gave the records for five years. It so happened that there was at Exeter a great excess of brilliancy in April for those five years if you added them together. In one of those years there was no drop in May, but in the other four there had been. He had a long chart on which he plotted all the 1896 measurements so as to give an idea of the general result, like a composite photograph. The instrument gave a record of the passage of clouds, and his hobby was to watch the clouds. It cost little to make the instrument, and he wished somebody would make one and experiment with it, when he felt sure they would find it interesting and a valuable means of comparing the weather of one day with that of another.

Howard Medal Award, 1923.

The Howard silver medal for 1923 has been awarded to Cadet J. C. Needham of H.M.S. "Worcester" for the best essay on "Tropical Storms."

Until 1920 the medal had been competed for by the cadets of the "Worcester" alone, but starting with the present year the award has in addition been open to cadets of the "Conway" and of the Nautical College, Pangbourne.

The examiner reports that the general standard of the essays was good, and showed that the subject had been carefully studied.

Lectures on Weather and Crops.

Mr. R. H. Hooker, a Past President of this Society, will give four lectures at University College, London, on "The Weather and the Crops," on Fridays, November 9, 16, 23 and 30, at 5.30 P.M. These lectures will form the first part of a course of "Jevons Memorial" Lectures, and the second part of the course will be given during the session 1924–25. The lectures are open to the public, and are free.

Meteorology in Education.

By invitation of the Royal Meteorological Society, the Geographical Association and the Science Masters' Association, a Conference devoted to the consideration of the place of meteorology in education will be held at the Birkbeck College, Bream's Buildings, Fetter Lane, London, E.C.4, on Thursday, January 3. Sir Napier Shaw will preside. The time of meeting will be announced in due course.

The subjects of discussion will be such as "The place of meteorological observations in the school course," and "The teaching of meteorology and climatology in schools from (1) the physical and (2) the geographical standpoint." Fellows of the Royal Meteorological Society who wish to take part in the discussion are invited to communicate with Mr. F. J. W. Whipple at 6 Addison Road, Chiswick, W.4, as soon as possible.

The Conference precedes the Annual General Meeting of the Geographical Association to be held in the same building. Professor Sir Richard Gregory as President of the Association will deliver an address on "British Climate in Historic Times." All who are present at the Conference are invited to stay for the address.

NOTES ON THE "SUMATRAS" OF THE MALACCA STRAITS.

By Captain E. E. Benest, F.R.Met.Soc.

[Received March 20—Read May 16, 1923.]

On account of local conditions small systems of varying pressures are set up and bring into being the winds experienced in different parts of the world, each having their special characteristics and usually their particular local names. These minor circulations are of importance to the peoples residing within the area over which their influence is exerted, and are of much interest to the meteorologist in his investigations into the circulation of the atmosphere. As scientific inquiry constantly seeks the simplification of the subject investigated, so it is constantly inquiring into the minor elements of the main problem with the hope of bringing them into line to form an homogeneous whole. It is with this point in view that I have ventured to attempt to describe one of these minor circulations, in the hope that the observations I have been able to make may prove of general interest.

The "Sumatra" (Malay = "Angin Ribut") of the Malacca Straits is well known to those who ply their trade up and down the adjacent coasts of Sumatra and Malaya. These squalls usually blow from the south-west, and are more frequent between the months of April and October. A greater number is experienced between Malacca and Pulo Penang than between Malacca and Singapore; but on occasion the latter place is visited by these squalls, and cases are on record in which vessels, owing to a disregard of local warnings, have been driven ashore.

"Sumatras" always occur at night, generally between the hours of 9 p.m. and 3 a.m., and are nearly always accompanied by thunder, lightning, and torrential rain. The strength of the wind is estimated as "strong gale," with a velocity lying between 40-55 m.p.h. The squall is always accompanied by its characteristic cloud formation—a heavy arch or bank of cumulo-nimbus—which rises to a great height (I estimate to upwards of 7000 ft.) and rapidly spreads over the whole heavens. On several occasions I have observed light cirrus clouds to form above the main pack, and when this has been the case a very violent storm has usually followed.

Generally the wind does not break upon the vessel until the advancing edge of the cloud bank has arrived at a point situated at eleven o'clock with regard to the observer, supposing the observer to be at the centre of a vertical dial and facing three o'clock. But this is not an invariable rule. No great change in the direction of the wind takes place throughout the squall, though shifts of two or three points have been noted. Rain usually falls with the first gust of wind, but may be very much delayed and not arrive until an hour or more afterwards. Thunder and lightning always are present: the lightning appears, however, to be mostly of the cloud to cloud type, and the flashes are of great brilliance.

The duration of these "Sumatras" seldom exceeds two hours; they are often very local, and do not appear to travel far inland, for they are mostly lost at a distance of thirty miles from the coast. Thus, of a number of storms recorded at Pintu Gedong, Port Swettenham, quite 60 per cent have disappeared or have lost all force by the time they arrive in Kuala Lumpur, 28 miles away, and this in spite of the fact that the intervening country is fairly flat.

DISCUSSION.

The PRESIDENT (Dr. C. Chree) said that if a completely satisfactory explanation were a necessary accompaniment to the description of a natural phenomenon—a view he personally did not share—he was afraid that many interesting phenomena such as that described by Captain Benest would have to remain undescribed. They were indebted to Sir David Wilson-Barker for the lucid account he had given of the facts in the paper.

Mr. M. T. SPENCE writes:—Factors which are probably of considerable importance in causing these squalls are:

1. The SW monsoon, since it has travelled from colder latitudes, must have a comparatively steep lapse rate of temperature when it reaches Sumatra.
2. Air after crossing the ridge of mountains on the west of Sumatra has an adiabatic lapse rate of temperature up to about 7000 ft. (the height of the mountain ridge) and must be comparatively dry near the surface.
3. Air crossing the Malacca Straits picks up moisture.

(1) and (2) may to some extent account for the heavy rain and thunderstorms experienced during the occurrence of Sumatras.

(3) may go to explain why the rain and thunder are experienced on the Malay side and not on the Sumatra side of the Straits.

Discussions at the Meteorological Office.

Meetings for the discussion of recent contributions to meteorological literature will be resumed at the Meteorological Office during the session 1923-4. The meetings will be held on alternate Mondays at 5 P.M., beginning on Monday, October 15, when the discussion will be opened by Sir Napier Shaw, F.R.S.

Subsequent meetings are as follows:—

1923—October 29; November 12, 26; December 10.
1924—January 21; February 4, 18; March 3, 17, 31.

Meteorological Instruments at Mien-chow, West China.

The Council regret to announce the death of the Rev. F. J. Watt, to whom a set of meteorological instruments was lent for use at the Church Missionary Society's Station at Mien-chow, Sze-chuan, Western China. From information published in the press it appears that Mr. Watt and another clergyman of the Church Missionary Society were murdered by Chinese bandits near Mien-chow on August 14.

The instruments lent to Mr. Watt were taken out by him in March 1922, and arrived safely notwithstanding a minor shipwreck and other small disasters. They were a source of much interest to the boys in the Mission School, and excellent records of observations were sent to the Society from October 1922. The return for June 1923, which was posted early in August, came to hand after the news of Mr. Watt's death had reached this country.

REPORT ON THE PHENOLOGICAL OBSERVATIONS IN THE BRITISH ISLES, FROM DECEMBER 1921 TO NOVEMBER 1922.

No. 32, New Series.

By J. EDMUND CLARK, B.A., B.Sc., and IVAN D. MARGARY, M.A.

In the death of their colleague, Henry Bridger Adames, last December, the Phenological Committee have sustained a heavy loss, the full effect of which will not quickly pass away. An obituary notice appeared in the April *Journal*. Mr. Adames brought to our work peculiarly valuable gifts, especially as regards the classification of records and co-ordination of results. He had shared the work for eight years and was already actively preparing to deal with the 1922 returns. Almost the last work in which he joined was an appeal, with the object of lessening the gaps widely separating stations in several districts. This was sent to various papers and periodicals with most gratifying results, especially through the *Times* and *Nature*. At present our chief desideratum is at least one station in the Scilly Isles and, most especially, in the Isle of Man. Meanwhile stations for 1922 total 239, thus exceeding by 27 the preceding high-water mark of 1920.

We again express our great indebtedness to Mr. E. Kay Robinson, the Editor of *Countryside*,[1] and to Mrs. Dent, President of the Wild Flower Society, for keeping our work before their clientèle and thus introducing fresh stations. To all our observers, on behalf of the Society, we express the warmest appreciation for their co-operation.

The numbers in the tables show the days elapsed from New Year, midnight. Hence, December 1 is – 31, February 1 is 32, and so on.

Cost of printing still compels utmost condensation far beyond our wishes. We again omit from the printed tables all records under seven entries in III. except in sparse districts; in VI., of under three birds or three insects; in VII., of under nine out of the twenty-eight migrants. But all records are tabulated and used in working out the mean values. They are of course kept for future reference, as well as the original observation forms and a digest of notes abstracted from them.

Last autumn an important step was taken towards collaboration between your Committee and the Ministry of Agriculture and Fisheries, mainly in connection with Agricultural Colleges. Considerable progress has been made in preparation for 1924.

Weather Summary: "A Cool Year."

"Abnormal" in 1922 appears only once in the Meteorological Office Annual Summary, compared with its five-fold use in 1921. This reference was to the October dryness. "Unusual" was applied to its extension over November and to the May high temperatures.

The winter months were mainly on the warm side, especially

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[1] This capital little monthly for field naturalists can be had from 8 Glamorgan Road, Hampton Wick, Middlesex.

TABLE I.—VARIATIONS FROM THE AVERAGE IN TEMPERATURE, RAINFALL, SUNSHINE, 1921–22.

Mean Daily Temperature.

MONTHS.	DISTRICTS.										
	Eng. S.W.	Ire. S.	Eng. S.E.	Mid. Co's.	Eng. E.	Eng. N.W.	Ire. N.	Scot. W.	Eng. N.E.	Scot. E.	Scot. N.
				M.O.	district nu	mbers.					
	8, 11.	10.	5.	4.	3.	7.	9.	6.	2.	1.	0.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
December .	+2·5	+4·5	+2·7	+4·0	+3·6	+4·0	+5·0	+3·4	+4·0	+4·0	+2·9
January .	+0·9	+1·1	+0·8	0·0	+0·2	+0·2	+1·0	−0·8	−1·2	−1·5	−0·6
February .	+1·5	+2·0	+1·6	+0·7	+1·4	+1·0	+2·1	+0·7	−0·1	0·0	+0·6
Winter .	+1·6	+2·5	+1·7	+1·6	+1·7	+1·7	+2·7	+1·1	+0·9	+0·8	+1·0
	°	°	°	°	°	°	°	°	°	°	°
March .	−0·9	0·0	−0·3	−0·9	−0·1	−0·6	+0·2	+0·6	−0·8	0·0	+0·9
April .	−3·2	−3·7	−3·0	−3·6	−2·9	−3·6	−3·8	−3·6	−2·8	−3·9	−2·9
May . .	+2·8	+2·5	+3·5	+4·7	+4·5	+2·3	+2·4	+0·7	+4·9	+1·5	+0·4
Spring .	−0·4	−0·4	+0·1	+0·1	+0·5	−0·6	−0·4	−0·8	+0·4	−0·8	−0·5
	°	°	°	°	°	°	°	°	°	°	°
June . .	+0·2	−0·3	+0·6	+0·3	+0·5	−0·5	−1·3	−1·3	+1·1	−1·2	−1·3
July . .	−3·3	−3·2	−2·8	−3·1	−2·5	−3·3	−2·9	−2·8	−2·3	−3·3	−2·2
August .	−3·1	−1·6	−2·8	−2·9	−2·2	−2·6	−2·0	−2·1	−2·0	−2·6	−1·7
Summer .	−2·1	−1·7	−1·7	−1·9	−1·4	−2·1	−2·1	−2·1	−1·1	−2·4	−1·7
	°	°	°	°	°	°	°	°	°	°	°
September.	−1·2	−0·4	−1·8	−1·2	−1·3	−1·6	−0·9	−1·2	−1·3	−1·8	−1·3
October .	−2·5	−0·5	−2·5	−1·8	−1·0	−1·5	0·0	−1·0	−1·0	−1·2	−0·7
November.	−1·5	+1·0	−2·2	−0·6	−1·3	+0·1	+1·9	+0·5	−0·5	+1·0	+0·7
Autumn .	−1·7	0·0	−2·2	−1·2	−1·2	−1·0	+0·3	−0·6	−0·9	−0·7	−0·4
YEAR.	°	°	°	°	°	°	°	°	°	°	°
Dec.-Nov.	−0·7	+0·1	−0·5	−0·3	−0·1	−0·5	+0·1	−0·6	−0·2	−0·8	−0·4

+ indicates above the average, − below it.

Total Rainfall.

[25 millimetres practically equal 1 inch; hence 0·04 inch equals 1 mm.]

	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
December .	−61	−46	−33	−18	−19	+15	+ 1	+40	−17	+ 1	+89
January .	+24	+18	+33	+30	+41	+14	+24	+26	+23	+15	−32
February .	+24	+23	+12	+27	+14	+23	+31	+32	+16	+ 5	+20
Winter .	−13	−05	+12	+39	+36	+52	+56	+98	+22	+21	+77
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
March .	+ 4	−28	+ 2	+ 6	− 1	−16	−28	−36	− 3	−15	−41
April .	+23	− 1	+34	+26	+22	+ 4	+19	+10	+ 6	+23	−14
May . .	−27	−18	−21	−25	−25	−25	−13	+23	−23	−18	+80
Spring .	0	−47	+15	+07	−04	−37	−22	−03	−20	−10	+25

TABLE I.—Variations from the Average—*continued.*

Total Rainfall—continued.

Months.	Districts.										
	Eng. S.W.	Ire. S.	Eng. S.E.	Mid. Co's.	Eng. E.	Eng. N.W.	Ire. N.	Scot. W.	Eng. N.E.	Scot. E.	Scot. N.
				M.O. district numbers.							
	8, 11.	10.	5.	4.	3.	7.	9.	6.	2.	1.	0.
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
June . .	− 28	− 31	− 12	− 29	− 14	− 10	− 11	+ 2	− 20	− 11	− 12
July . .	+ 30	+ 6	+ 23	+ 41	+ 49	+ 27	+ 25	+ 7	+ 43	+ 22	+ 1
August .	+ 13	+ 8	+ 13	+ 52	− 9	+ 13	− 5	− 21	+ 1	− 22	− 17
Summer .	+ 15	− 17	+ 24	+ 64	+ 26	+ 30	+ 09	− 12	+ 24	− 11	− 28
	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
September .	+ 7	+ 12	+ 2	+ 8	+ 20	+ 12	+ 23	− 13	+ 26	+ 1	− 23
October .	− 74	− 67	− 53	− 57	− 40	− 78	− 53	− 57	− 45	− 34	− 57
November .	− 56	− 56	− 36	− 34	− 21	− 48	− 42	− 41	− 35	− 32	− 33
Autumn .	− 123	− 111	− 87	− 83	− 41	− 114	− 72	− 111	− 54	− 65	− 113
Year.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.
Dec.-Nov.	− 121	− 180	− 36	+ 27	+ 17	− 69	− 29	− 28	− 28	− 65	− 39

Daily Mean Sunshine.

	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
December .	− 0·21	− 0·19	− 0·30	+ 0·07	− 0·01	+ 0·15	− 0·25	...	+ 0·39	+ 0·30	− 0·20
January .	− 0·11	+ 0·28	− 0·14	− 0·15	− 0·55	+ 0·23	+ 0·37	...	− 0·25	− 0·12	− 0·17
February .	− 0·02	+ 0·11	+ 0·75	+ 0·29	+ 0·82	+ 0·03	+ 0·32	...	+ 0·36	− 0·48	− 0·03
Winter .	− 0·11	+ 0·07	+ 0·10	+ 0·07	+ 0·09	+ 0·14	+ 0·15	...	+ 0·17	− 0·10	− 0·13
	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
March .	+ 0·15	+ 0·47	− 0·74	− 0·98	− 0·46	+ 0·38	+ 1·11	...	− 1·18	− 0·25	− 0·17
April .	+ 0·31	+ 0·11	− 0·33	− 0·37	+ 0·10	+ 0·82	+ 1·04	...	+ 0·37	+ 0·02	+ 1·51
May . .	+ 1·32	+ 0·47	+ 2·50	+ 1·57	+ 2·29	+ 0·38	− 0·63	...	+ 1·50	+ 0·37	− 1·00
Spring .	+ 0·59	+ 0·35	+ 0·48	+ 0·07	+ 0·64	+ 0·53	+ 0·51	...	+ 0·23	+ 0·03	+ 0·11
	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
June . .	+ 0·26	− 0·95	+ 0·32	+ 1·02	+ 0·60	− 0·12	− 0·59	...	+ 1·00	− 0·07	+ 0·02
July . .	− 0·90	+ 0·04	− 1·48	− 1·23	− 1·67	− 0·71	− 0·48	...	− 1·48	− 0·90	+ 0·42
August .	− 1·96	− 1·34	− 1·70	− 1·45	− 1·16	− 1·21	− 1·46	...	− 0·65	− 0·54	+ 0·71
Summer .	+ 0·87	− 0·75	− 0·95	− 0·55	− 0·74	− 0·68	− 0·84	...	− 0·38	− 0·50	+ 0·38
	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
September .	− 0·94	− 0·95	− 1·03	− 1·45	− 0·56	− 1·23	− 0·98	...	− 1·60	− 1·09	− 0·50
October .	+ 0·92	+ 0·20	+ 0·71	+ 0·53	+ 1·02	+ 1·01	+ 0·66	...	+ 0·59	+ 0·43	+ 0·79
November .	− 0·08	− 0·36	− 0·27	+ 0·25	− 0·21	+ 0·11	− 0·40	...	+ 0·80	+ 0·40	− 0·09
Autumn .	− 0·03	− 0·37	− 0·20	− 0·22	+ 0·08	− 0·04	− 0·24	...	− 0·07	− 0·09	+ 0·07
Year.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
Dec.-Nov.	− 0·11	− 0·17	− 0·14	− 0·16	+ 0·02	− 0·01	− 0·11	...	− 0·01	− 0·16	− 0·11

December (1921), but occasional frosty interludes hindered prematureness. Before mid-March a settled cold period supervened, lasting with slight breaks into May. This month opened with vegetation later than recent years, except 1917. During these five months rainfall and sunshine were nearly normal. Except in Ireland S., rainfall was in excess, but only in Scotland W. by over 0·5 inch. Sunshine was short in the Midlands and four east districts, but abundant in Ireland and England N.W., while Scotland N. gave a great excess in April. May and early June stand out for dryness, extreme temperature maxima, and equally striking sunshine abundance, save in Ireland N. and Scotland N. England S.E. averaged 2·5 hours daily excess; England E. little less. Yet the later summer dullness resulted in universal shortage for the year, except in East Anglia. For July to September this averaged well over the hour, save in England N.E. and Scotland N.E. and N.; returns for Scotland W. are lacking. The sunny and dry October and dry November largely saved the belated northern harvests. As notable was the associated universal coldness through these 5½ months and wetness from July to September, save for August in Scotland and England E. and N.E. Although the mean temperature for the ten districts was only 0°·5 less than the average, no single one had an excess. The Channel Isles were + 0°·1.

THE EIGHT-MONTH ISOTHERMS AND ISOHELS (Lines of equal temperature and equal sunshine).

Fig. 1 naturally gives a strong southward shift of isotherms and isohels. In the latter, 4·5 replaces 5·5 from Norfolk to Cornwall; to the north the change is less. Derby and Notts form an enclave of diminished sunshine, as usual in the Midlands. In isotherms, that of 52° in the foot of Cornwall is little changed, thanks to sea influence, but 51° includes only south Cornwall and adjacent S.W. Devon, instead of stretching from Beachy Head to Kerry with deep northward bends up the Severn and into the Irish Sea. The former bend is practically absent this year, as if driven out by the tremendous south loop of 48°, down from Whitby to Cambridgeshire, then curving up to the Lancashire coast and on to Stranraer. In the Scottish central lowlands an enclave below 46° replaces last year's loop of 48°.

THE FLORAL ISOPHENES (Lines of equal flowering dates[1]), Fig. 2.

This year, in addition to the 1922 isophenes, we are for the first time able to give floral isophenes for the 30-year averages, 1891 to 1920. The working out of these had only recently been completed by Mr. Adames and they form a fitting memorial to his skill. He was ably helped by Miss B. Farley of Chichester.

These average isophenes show well-defined areas of early and late dates, closely related to elevation; a fact pointed out in past years. Attention may be called briefly to (1) the early Severn uprush; (2) the late strip from north-east Norfolk to London and the high ground around it; (3) the late areas over the South Downs, Devon and Cornwall highlands, and Central Wales; (4) the extensive late area over Scotland (culminating in the central Lowlands), from whence late strips reach right down the Pennine chain to Birmingham and south-westward over northern Ireland.

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[1] The Scabious and Ivy are excluded from the mean dates used for the isophenes.

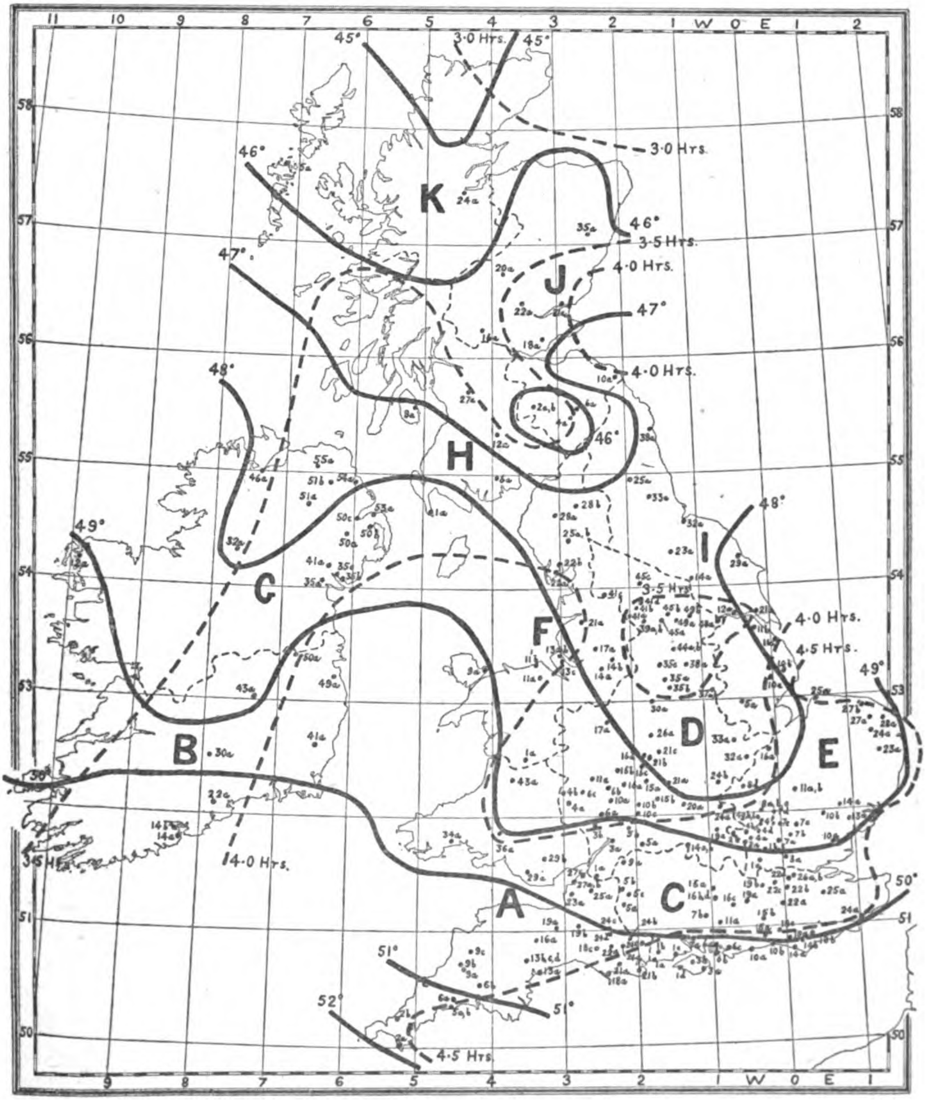


FIG. 1.—Isotherms (unreduced), or lines of equal temperature, and Isohels, or lines of equal sunshine, during the eight months December 1921 to July 1922; also Phenological Districts and Stations, 1922.

Isotherms ——— Isohels ▬ ▬ ▬ ▬ District Boundaries - - - - - -

The district letters and station numbers refer to Table II.

The 1922 isophenes are decidedly more complex than in former years, due apparently to the factor of elevation being intensified. Comparison with the isotherms and isohels must also be made. The result is a series of late enclaves south of the Humber-Mersey line, but also of three of early dates in W. Hants, W. Gloucester, and N. Bucks, respectively. Dates before 117 (April 27) only occur in these and in very restricted

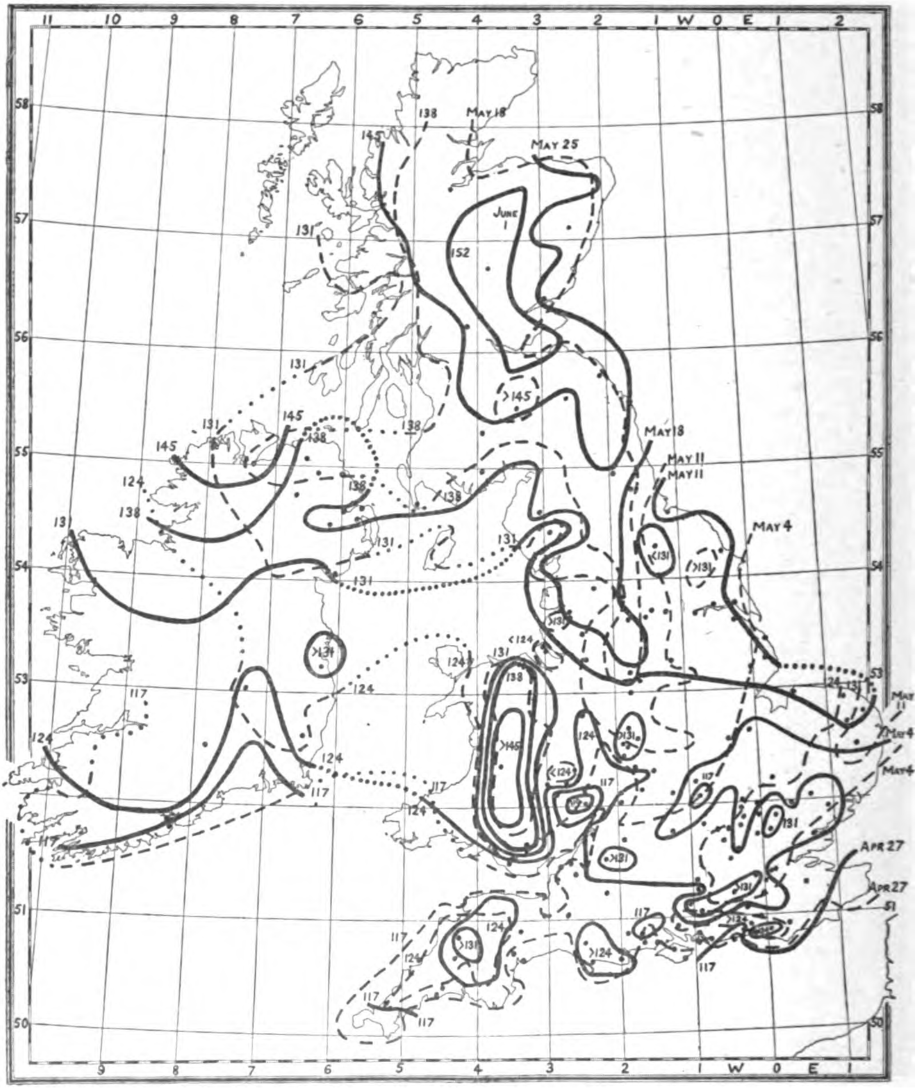


FIG. 2.—Weekly Floral Isophenes, or lines of equal flowering dates, from 110 to 152 days.

110 = April 20. 117 = April 27. 124 = May 4. 131 = May 11. 188 = May 18.
145 = May 25. 152 = June 1.

1922 ———— Average (30 years 1891–1920) - - - -

(The effect of high ground is clearly evidenced in all parts of the country.)

of late enclaves south of the Humber-Mersey line, but also of three of early dates in W. Hants, W. Gloucester, and N. Bucks, respectively. Dates before 117 (April 27) only occur in these and in very restricted

TABLE II.—LIST OF THE STATIONS FURNISHING PLANT, INSECT, AND BIRD RECORDS, WITH THE NAMES OF THE OBSERVERS.

(*, Plant records only; †, Bird and Insect records only.)

The numbers in brackets following the District Letters represent the Meteorological Office designations.
Heights in brackets are approximations from Contour Road Books.

STATION.	COUNTY.	Height above Sea-level.	OBSERVER.
A (8).		Ft.	Observers: 37 - 6 + 6 = 37.
†10a. Guernsey (11)	Channel Is.	...	B. T. Rowswell.
2a. The Lizard	Cornwall	250	Miss P. Coleman Smith.
2b. Camborne	Cornwall	370	F. Osborne, F.R.Met.Soc.
5a. Polperro	Cornwall	100	Miss H. M. M. Perrycoste.
5b. Polperro	Cornwall	80	F. Rilstone.
6a. Duloe	Cornwall	480	C. S. Hooper.
9a. Launceston	Cornwall	500	Rev. T. N. H. Smith-Pearse.
9b. Hexworthy	Cornwall	270	R. B. Rogers.
6b. Tavistock	Devon	460	W. J. Monk.
9c. Clawton	Devon	400	Rev. H. H. Harvey.
13a. Exmouth	Devon	20	D. E. Civil.
*13b. Exeter	Devon	...	Mrs. E. Cornish.
13c. Exeter	Devon	100	A. H. Rousham.
13d. Exeter	Devon	120	H. C. Biddell.
16a. Tiverton	Devon	270	Miss M. E. Gill.
18a. Weymouth	Dorset	100	N. M. Richardson.
21a. Winfrith	Dorset	130	The Misses Haines.
18c. Hilton	Dorset	470	Miss E. E. Woodhouse.
21b. Corfe Castle	Dorset	50	Rev. C. B. Hughes.
22a. Pulham	Dorset	350	Rev. J. Ridley.
24a. Blandford	Dorset	(150)	W. Ford.
24b. Edmondsham	Dorset	100	H. W. Southcott.
†24c. Shaftesbury	Dorset	(650)	Miss Crispin.
24d. West Melbury	Dorset	650	P. W. Druce.
24e. Verwood	Dorset	150	J. H. Salter, D.Sc.
19a. Bradford, Taunton	Somerset	150	F. W. Mathews.
19b. Langport	Somerset	20	N. Packwood.
23a. Winscombe (Crooks Peak)	Somerset	110	W. H. Stephens.
25a. Redhill, Wrington	Somerset	550	J. F. and E. Jeffrey.
27a. Weston, Bath	Somerset	150	T. H. Green.
27b. Weston, Bath	Somerset	200	Miss I. Norman.
27c. Portishead	Somerset	250	T. Clarke.
29a. Bridgend	Glamorgan	80	H. J. Randall, LL.B.
29b. Pontypridd	Glamorgan	(200)	B. Riley, B.E.N.A.
34a. Laugharne	Carmarthen	50	J. F. Thomas.
36a. Llandilo	Carmarthen	300	D. E. Stephens.
43a. Hafod, Devil's Bridge	Cardigan	580	D. H. Dunn, F.R.H.S.
B (10).			Observers: 5 - 1 + 4 = 8.
14a. Monkstown	Co. Cork	200	Miss E. M. Ferguson.
14b. Passage West	Co. Cork	350	J. Mintern, F.R.Met.Soc.
†22a. Lismore	Waterford	...	A. J. King.
30a. Cashel	Tipperary	260	E. W. Montagu Murphy, F.R.Met.Soc.
41a. Ferns	Wexford	260	C. E. J. Greene, M.A., D.Sc.
43a. Mountmellick	Queen's Co.	250	Mrs. A. E. Pim.
49a. Old Connaught, Bray	Wicklow	250	Miss St. J. Whitty.
50a. Johnstown Bridge	Kildare	...	Miss A. M. McNally, B.E.N.A.
C (5).			Observers: 30 - 6 + 15 = 39.
5a. Warminster	Wilts	400	J. Bartlett.
5b. Holt, Trowbridge	Wilts	150	Mrs. W. Gee.
5c. Bratton	Wilts	...	C. E. Tucker.
9a. Sherston	Wilts	...	A. D. Norton.
†1a. Bournemouth	Hants	120	F. G. Penrose, M.D.
1b. Ringwood	Hants	80	L. W. Hinxman, F.R.S.E.

TABLE II.—List of the Stations with the Names of Observers—*continued.*

1c. Lymington	Hants	0	P. A. Ouvry.
1d. Totland Bay	Isle of Wight	140	J. Dover, F.R.Met.Soc.
3a. Shanklin	Isle of Wight	200	R. H. Fox.
3b. Newport	Isle of Wight	50	F. Morey.
6a. Havant	Hants	40	H. Beeston, M.B.O.U., M.C.S., F.R.Met.Soc.
6b. Hayling Island	Hants	0	Miss M. T. Hillard.
7a. Botley	Hants	40	Lady M. S. Jenkyns.
7b. West Meon	Hants	470	Major and Mrs. G. E. Galbraith.
11a. Petersfield	Hants	400	G. Abbey.
16a. Fleet	Hants	250	Miss D. Reid.
6c. Chichester	Sussex	250	Miss B. Farley.
10a. Littlehampton	Sussex	(20)	C. T. Gardner.
10b. Hove	Sussex	160	E. J. B. Sopp, F.E.S.
14a. Seaford	Sussex	200	J. F. Thomas.
†14b. Alfriston	Sussex	0	Mrs. Faulkner Jefferies.
15a. Devil's Dyke	Sussex	340	P. H. Laker.
15b. Horsham	Sussex	140	H. Dinnage.
18a. Lewes	Sussex	100	R. Morris.
18b. Hellingly	Sussex	170	Mrs. M. Stroud.
18c. Ditchling	Sussex	220	F. F. Wood.
16d. Wrecclesham	Surrey	365	Miss Tinne.
16b. Farnham	Surrey	300	Mrs. H. M. Gohery.
†16c. Hambledon, Godalming	Surrey	...	E. Parker.
19a. Cranleigh	Surrey	180	Miss H. E. Ravenscroft.
19b. Epsom District	Surrey	200	Miss D. E. Theak, B.E.N.A.
22a. Lingfield	Surrey	270	Mrs. Margary.
22b. Warlingham	Surrey	600	A. Beadell.
22c. Purley	Surrey	350	J. E. Clark, B.A., B.Sc., F.R.Met.Soc., and friends.
22d. Hayes	Kent	280	Miss A. W. Morris.
24a. Lympne District	Kent	350	J. G. Goodyear, F.R.Met.Soc.
25a. Maidstone	Kent	100	H. J. Elgar.
26a. Bromley	Kent	150	J. B. Dalton.
*26b. Bromley	Kent	150	H. M. Singleton.
D (4).			Observers: 47 − 6 + 13 = 54.
1a. Bristol	Gloucester	(80)	N. C. W. Hoyle.
3a. Lydney Park	Gloucester	180	H. W. Miles, B.Sc., F.E.S.
5a. Cirencester	Gloucester	400	W. H. Leach.
5b. Cheltenham	Gloucester	(200)	Miss F. M. Heward.
6a. Dymock	Gloucester	120	Miss M. Peake.
3b. Ross	Hereford	210	Miss M. L. Southall.
4a. Weobley	Hereford	320	Miss M. S. Hall, F.R.Met.Soc.
4b. Staunton-on-Arrow	Hereford	400	Rev. Preb. S. Cornish Watkins.
6b. Bromyard	Hereford	400	Miss M. A. Philpott.
6c. Kimbolton	Hereford	420	Miss E. Hutchinson.
10a. West Malvern	Worcester	600	Mrs. E. Kensington.
10b. Evesham	Worcester	100	R. Gibbins.
11a. Tenbury	Worcester	310	Fredk. Lowe.
†16a. Hampton Lovett	Worcester	130	W. J. Blakeway.
16b. Wolverley (Cookley)	Worcester	...	T. J. Beeston.
16c. Barnt Green, Birmingham	Worcester	650	Miss M. Gibbins.
10c. Ashorne	Warwick	160	G. T. Osborn, F.R.Met.Soc.
15a. Whernalls, Alcester	Warwick	230	E. W. and R. H. R. Jephcott.
15b. Stratford-on-Avon	Warwick	120	A. C. Ancill.
16d. Quinton, Birmingham	Warwick	600	W. Haycock, B.E.N.A.
21a. Rowington	Warwick	...	Scholars, Rowington School.
21b. Erdington	Warwick	420	E. D. Moore, B.Sc.
21c. Nether Whitacre	Warwick	...	J. Steele.
17a. Edgmond, Newport	Shropshire	220	A. Roebuck.
14a. Oxford	Oxford	210	W. H. Piper, F.R.Met.Soc.
14b. Oxford	Oxford	210	F. A. Bellamy, M.A., F.R.A.S.
20a. Farnborough	Oxford	520	Miss C. Prater, A.R.R.C.
19a. Weston Turville	Bucks	220	G. Eland.
24a. Bletchley	Bucks	340	A. S. King.
24b. Northampton	Northants	300	H. N. Dixon, M.A., F.L.S.
32a. Oundle	Northants	140	F. W. Jane.
33a. Ketton	Rutland	290	Rev. A. H. Snowden.
26a. Lichfield	Stafford	500	W. B. Pinder.
30a. Mayfield, Ashbourne	Derbys	420	F. H. Wright.
35a. Somersal Herbert	Derbys	320	N. H. FitzHerbert.
35b. Matlock	Derbys	550	Maj. T. B. Franklin, F.R.S.E., F.R.Met.Soc.
35c. Eyam	Derbys	900	V. H. Lucas.

TABLE II.—List of the Stations with the Names of Observers—*continued.*

37a. Newark-on-Trent	Notts	50	F. R. Larkin.
37b. Balderton, Newark	Notts	50	E. Tillin.
38a. Hodsock	Notts	60	Miss A. Mellish, F.R.H.S.
39a. Huddersfield	Yorks, W.R.	330	C. Mosley, M.B.O.U.
39b. Kirkheaton	Yorks, W.R.	250	E. Fisher.
†41a. Hebden Bridge	Yorks, W.R.	300	W. Greaves.
41b. Wilsden	Yorks, W.R.	600	E. P. Butterfield.
41c. Grindleton	Yorks, W.R.	380	Miss M. E. Ackerley.
41d. Cross Hills, Keighley	Yorks, W.R.	350	J. Holmes.
44a. Sitwell Vale	Yorks, W.R.	300	G. Howard.
44b. W. Melton, Newhill	Yorks, W.R.	230	J. H. Payne, B.E.N.A.
45a. Middlestown	Yorks, W.R.	420	J. Hooper.
45b. Altofts, Normanton	Yorks, W.R.	120	H. G. Townsend.
45c. Menston-in-Wharfedale	Yorks, W.R.	400	Miss W. M. Wheatley.
48a. Goole	Yorks, W.R.	10	J. Harrison.
49a. Red Hill, Castleford	Yorks, W R.	230	H. England.
49b. Ferrybridge (Fairburn)	Yorks, W.R.	120	W. G. Bramley.
E (3).			Observers: 27 − 6 + 16 = 37.
1a. Harrow	Middlesex	150	Miss M. E. Collington.
1b. New Barnet	Herts	300	A. V. Daniels.
†1c. Barnet	Herts	(400)	R. A. Woolner.
2a. Berkhamsted	Herts	400	Mrs. E. Mawley.
2b. Tring	Herts	450	T. G. Dale.
4a. St. Albans	Herts	270	Herts. Institute of Agriculture.
4b Harpenden	Herts	400	J. L. Hodgkinson.
4c. Harpenden	Herts	400	Miss S. Salisbury.
4d. Tewin, Welwyn	Herts	200	G. Lamb and Scholars.
4e. Knebworth	Herts	400	C. A. Robinson.
4f. Bennington	Herts	410	Miss E. A. Parker, F.R.Met.Soc.
4g. Hitchin	Herts	300	H. C. Littlebury.
*4h. Hitchin	Herts	200	R. Morse, F.R.H.S.
†4i. Hitchin	Herts	...	A. H. Foster.
7a. Birch Green	Herts	240	F. Rayment.
7b. Sawbridgeworth	Herts	350	H. S. Rivers.

7c. Braughing	Herts	250	J. T. Boorer.
7d. Buntingford	Herts	300	A. G. Freeman and E. F. Scrivener.
7e. Stanstead Abbotts	Herts	100	F. H. Brown, B.E.N.A.
8a. Letchworth	Herts	320	W. P. Westell, F.L.S.
†8b. Letchworth	Herts	300	R. Palmer, F.E.S.
8c. Letchworth	Herts	300	F. H. Poppy and Scholars.
8d. Bedford	Bedfords	80	Mrs. Rait Kerr, B.E.N.A.
†3a. Woodford	Essex	300	Dr. Ethel U. Vaudrey.
10a. Maldon	Essex	(80)	W. E. Cooper, B.E.N.A.
10b. Halstead	Essex	140	E. T. Adams, Lieut., R.N.V.R., and A. Kidd.
13a. Lexden	Essex	90	S. F. Hurnard.
14a. Ballingdon	Essex	150	C. F. D. Sperling.
11a. Cambridge	Cambridge	50	Mrs. M. S. Willis.
†11b. Cambridge	Cambridge	(50)	E. H. Warmington.
16a. Thorney	Cambridge	0	A. Whitlock and Scholars.
23a. Bungay	Suffolk	120	H. B. Dobbie, F.R.H.S.
24a. Norwich	Norfolk	100	A. W. Preston, F.R.Met.Soc.
25a. Hunstanton	Norfolk	50	Miss F. E. Johnson.
27a. Hevingham, Rippon Hall	Norfolk	90	Major H. P. Marsham.
27b. Holt	Norfolk	200	Gresham's School, N.H.S.
28a. Brunstead, Stalham	Norfolk	30	Rev. M. C. H. Bird.
F (7).			Observers: 13 − 2 + 6 = 17.
†1a. Caersws	Montgomery	(400)	T. C. Swain.
9a. Beaumaris	Anglesey	160	Miss E. Ridsdale.
*11a. St. Asaph	Flints	480	Rev. R. S. Corish, S.J.
11b. Meliden	Flints	90	R. H. Day.
13a. Birkenhead	Cheshire	130	A. C. Fraser.
13b. Birkenhead	Cheshire	(20)	E. Pickard.
13c. Higher Tranmere, Birkenhead	Cheshire	110	Mrs. F. M. Dallman.
14a. Barnton, Northwich	Cheshire	170	G. Owen, B.E.N.A., F.R.Met.Soc.
14b. Altrincham	Cheshire	100	Altrincham and District, N.H. and L.S.

TABLE II.—LIST OF THE STATIONS WITH THE NAMES OF OBSERVERS—*continued.*

17a. Leigh	Lancs	100	G. Brazier.
21a. Leyland, Worden	Lancs	130	H. Nowell ffarington, F.R.Met.Soc.
22a. Urswick, Ulverston	Lancs	150	J. Dobson.
†22b. Ulverston	Lancs	30	H. B. Turney.
†25a. Ambleside	Westmorland	140	A. Astley, M.B.O.U.
25b. Ambleside	Westmorland	220	Miss A. C. Drury.
28a. Keswick	Cumberland	300	J. Glaisyer, F.R.Met.Soc.
28b. Johnby Hall, Greystone	Cumberland	800	Mrs. M. Leyborne Popham.
G (9).			Observers: 13 − 4 + 6 = 15.
12a. Belmullet	Mayo	60	Mrs. I. M. Bingham, B.E.N.A.
32a. Enniskillen	Fermanagh	200	J. P. Burkitt.
†35a. Killincoole	Louth	100	Rev. W. F. Johnson, M.A., F.E.S.
41a. Bessbrook	Armagh	300	S. E. Baillie.
35b. Rostrevor	Down	0	Miss L. E. Richards.
35c. Warrenpoint	Down	200	J. Nugent.
50a. Hillsborough	Down	250	N. H. Foster, F.L.S.
50b. Comber	Down	100	W. J. Quinn.
*53a. Bangor	Down	60	E. G. Ingold.
48a. Altnafoyle	Londonderry	400	T. Gibson.
51a. Magherafelt	Londonderry	200	Sister M. Borromeo Corbett.
50c. Belfast	Antrim	200	T. McCloy.
*51b. Loan, Cullybackey	Antrim	560	J. K. Forbes, B.A.
54a. Hazelbank	Antrim	420	R. J. Craig, F.R.Met.Soc.
55a. Ballymoney	Antrim	160	Mrs. B. W. Redpath.
H (6).			Observers: 6 − 1 + 0 = 5.
1a. Kirkmaiden	Wigtown	120	Rev. D. R. Williamson.
6a. Castle Douglas	Kirkcudbright	400	Miss L. M. Williams.
8a. Brodick	Arran	...	The Marchioness of Graham and Lady Mary Graham.
12a. Moniaive	Dumfries	350	J. Corrie, F.S.A. (Scot.).
†27a. Glenorchard, Torrance	Stirling	200	J. Bartholomew.
I (2).			Observers: 16 − 3 + 1 = 14.
5a. Cranwell	Lincs	240	— Bell.
10a. West Keal, Spilsby	Lincs	200	Miss E. M. Grantham.
10b. Hagworthingham	Lincs	240	The Rev. Canon Claye, D.D.
11a. Cleethorpes	Lincs	40	Miss R. M. Farmeroy, B.A.
11b. Thornton Abbey	Lincs	30	J. H. and E. Davey.
12a. S.E. Yorks	Yorks, E.R.	250	E. W. Wade (North Ferriby).
†14a. York	Yorks, E.R.	80	S. H. Smith.
21a. Hull	Yorks, E.R.	(50)	C. E. Jacklin.
23a. Thirsk	Yorks, N.R.	120	A. B. Hall.
29a. Scarborough	Yorks, N.R.	90	A. J. Burnley.
32a. Acklam, Middlesbro'	Yorks, N.R.	50	F. Coltman, B.E.N.A.
33a. Lanchester	Durham	400	E. A. Leigh.
25a. Corbridge-on-Tyne	Northumb.	200	A. W. Price.
38a. Embleton	Northumb.	100	H. B. Herbert.
J (1).			Observers: 9 − 3 + 5 = 11.
2a. Broughton	Peebles	630	R. J. Hogg.
†2b. Broughton	Peebles	800	A. C. Gairns.
4a. Selkirk	Selkirk	500	J. R. Simpson.
6a. Galashiels	Selkirk	600	J. Clapperton and J. Roseburgh.
10a. West Foulden	Berwick	250	J. H. Craw, F.R.Met.Soc.
18a. Kinglassie	Fife	300	N. M. Johnson, B.Sc., L.C.P.
16a. Callander	Perth	250	F. W. L'Amie, M.A., B.Sc.
20a. Tummel Bridge	Perth	500	D. McIntyre.
22a. Bankfoot	Perth	500	A. H. Mackenzie-Catton, F.L.S.
21a. Dundee	Forfar	300	J. Garriock, M.A., B.Sc.
*35a. Banchory	Kincardine	180	Miss W. M. Deans.
K (0).			Observers: 2 − 1 + 1 = 2.
†5a. Vallay, Lochmaddy	N. Uist	150	G. Beveridge.
24a. Kiltarlity	Inverness	160	J. C. Ferguson, M.A.

coastal portions of England S.E., S.W., and Ireland S. In 1921 this isophene crossed central Ireland to Anglesey, thence looping the Welsh highlands and back to Birkenhead, bending thence through the central Midlands to the Wash, whence north to Scarborough. Moreover, in 1922 the 131 isophene from Mayo to the Wash is everywhere south of the 124 line in 1921, whose course it approximately follows until the East Coast, which was then within the 117 line.

North of the Humber, Thirsk and Ambleside are warm centres. In the absence of records from Scotland N. the latest isophene is 152 (June 1) from the Forth around Edinburgh, past Blair Atholl, and embracing the central highlands of Aberdeen, Elgin, etc.

The few Irish stations outside Ulster give us 117 (April 27) only at Monkstown and Mountmellick, north of which isophene 124 appears to run. The central east coast gives a late enclave (138), while Londonderry (146) is the latest Irish station.

We thus get the extreme range of mean flowering as follows:—England, 103-145; Wales, 121-147; Scotland, 139-156; Ireland, 115-146; British Isles, April 13 to June 4. Corresponding values for 1921 are:—100-134; 113-135; 126-147; 102-134; April 10 to May 27. (These extremes are no indication of the means of Table IV., 144½ and 133.)

Comparing 1922 with the average isophenes, the difference in England, though in the main towards lateness, is not as a rule great, and certain early areas are slightly intensified. Areas in Essex, from London to Winchester, most of Dorset, Dartmoor, the south Wales coast, and East Coast around the Humber are over a week late. On the other hand, the early west Gloucester area is intensified locally by over two weeks and again at Yarmouth; in north Bucks and part of Staffordshire and Yorkshire 1922 seems to have been earlier than the average. Scotland was definitely behind, usually by at least a week. Ireland was also late except in small areas in Antrim and the extreme south-east.

Table IV. and Fig. 3 further elucidate the points emphasised above. Temperature deviations in Table I. explain the relative earliness of anemone and blackthorn in Ireland S. Scotland N. was least deficient in April, but hardly enough to account for the relative earliness of blackthorn, garlic hedge-mustard, and horse-chestnut. Obviously lack of stations here makes mean annual values of little weight. Only England N.E. is early, alone except England E. in having a plus temperature divergence up to August. But its June excess was largest, resulting, for instance, in black knapweed there being 15 days early. The lateness of the middle set of plants in all parts is largely countered by the earliness before April and after May. Hence the British Isles mean is only one day late. The need to condense explains the excision from Table V. of all but five years.

THE FOUR EARLY SPRING FLOWERS.—The dates in Table III.A, though preceding the specially cold period, are a week late on the 10 years' average. The relative earliness of these years accounts for at least half of this. Compared with the whole 30 years, the 10 years' average of the same five districts of Table V. is 4 days early, and the 1922 mean of Table III.A, 34·1, for these five gives us the 30 years' average date.

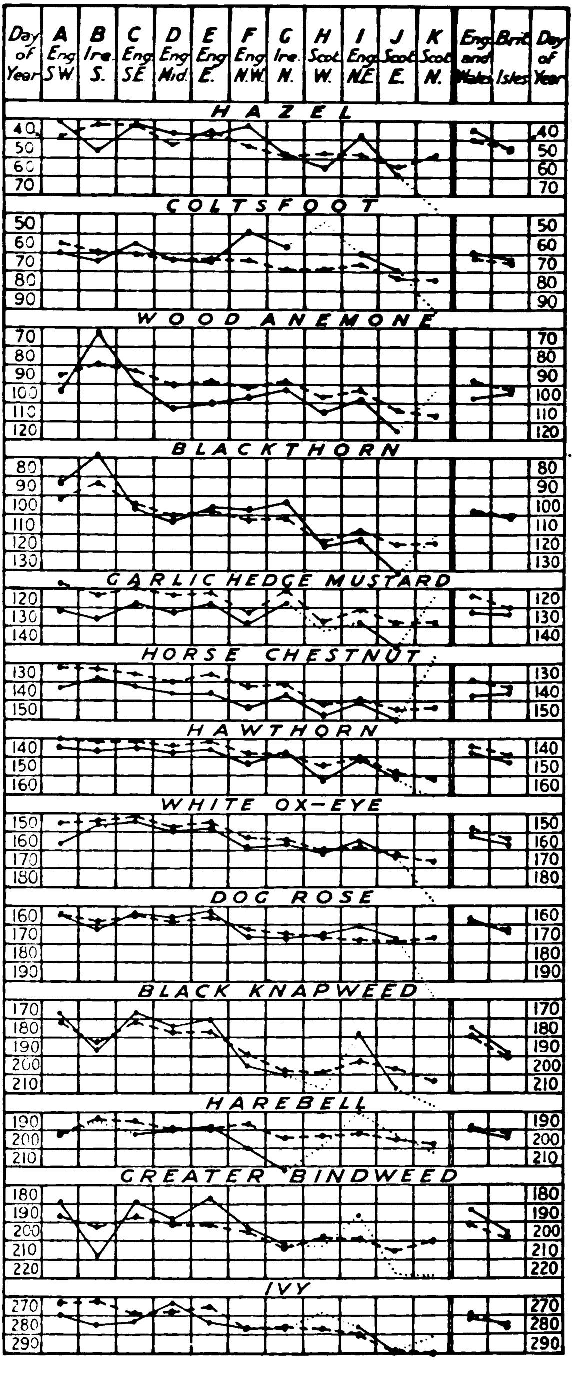


FIG. 3.—Dates of Flowering of Plants.

1922 ——— 30 years' average - - - - - - Conjectural . . . . . .

TABLE III.—Date (Day of Year) of First Flowering of Plants, 1922.

The dates in *italics* are interpolated or estimated, and have not been taken into consideration when calculating the means for Table IV., except for Harebell in B, and certain plants in H, J, and K. The figures immediately following the station names indicate the mean values used in drawing the isophenes, and in computing these, interpolated, as well as actual, dates have been utilised.

Explanation of date Numbers, December 1 is − 31 ; 31, − 1.

1-31 = Jan.	60–90 = March.	152-181 = June.	244-273 = Sep.
32–59 = Feb.	91-120 = April.	182-212 = July.	274-304 = Oct.
(Leap year 32-60)	121-151 = May.	213-243 = Aug.	305–334 = Nov.

Station.	Mean Value excluding Ivy and Scabious.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Ivy.	Devil's-Bit Scabious.
A (8)															
2b. Camborne .	118	40	41	103	75	102	122	121	146	156	154	*182*	*172*	270	...
5a/b. Polperro .	119	29	2	85	57	127	128	140	139	153	184	*204*	186	251	227
6a. Duloe .	119	19	36	60	*58*	127	144	141	149	159	167	*193*	181	281	225
9a. Launceston	129	*44*	53	*96*	79	*127*	142	136	158	158	163	*196*	*191*	...	...
9c. Clawton .	132	56	*76*	*106*	97	127	140	138	147	152	171	*194*	*180*	...	...
13a. Exmouth .	121	35	59	78	78	120	121	132	141	149	161	*191*	183	266	...
† Exeter .	122	31	67	96	86	122	126	125	152	149	167	*185*	162	268	229
16a. Tiverton .	122	39	53	100	67	124	132	130	147	154	159	*184*	170	275	229
18a. Weymouth .	130	*40*	*60*	110	89	127	130	130	145	159	*170*	*202*	197	280	...
18c. Hilton . .	126	22	99	89	69	129	139	138	147	155	154	195	177	255	186
21b. Corfe Castle	130	32	*93*	80	107	119	139	125	167	159	164	194	*186*	283	...
24b. Edmonds'm	119·	41	59	85	82	110	130	134	147	152	160	160	171	248	230
24e. Verwood .	112	4	26	76	71	115	130	130	141	150	159	175	172	255	186
19a. Bradford .	123	18	55	*88*	99	117	132	136	149	151	157	*191*	187	276	271
19b. Langport .	120	21	73	97	57	111	128	135	147	148	161	*188*	177	294	...
23a. Winscombe	124	33	64	99	81	124	123	132	153	156	169	*189*	171	253	190
25a. Wrington .	124	*27*	*61*	114	69	118	141	130	128	153	163*	205	179	254	217
27a. Weston, nr. Bath	121	8	44	74	89	121	133	134	158	159	163	207	161	264	234
27c. Portishead .	122	20	46	88	86	117	134	139	146	142	166	201	179	250	213
29a. Bridgend .	121	39	58	62	*92*	*125*	140	145	*133*	*131*	168	*190*	173	...	...
29b. Pontypridd	144	67	67	120	129	*139*	*150*	140	156	155	*184*	*213*	204	267	258
43a. Hafod . .	147	55	98	123	116	*134*	145	146	164	177	198	205	209	299	211
B (10)															
14a. Monkstown	117	36	*49*	62	41	*120*	130	133	129	*149*	*182*	*176*	*201*	...	..
14b. Passage West	134	61	*69*	*71*	85	*138*	113	143	157	159	198	*192*	217	272	232
30a. Cashel .	126	*25*	*52*	32	68	*131*	128	141	152	174	200	*194*	219	262	229
41a. Ferns . .	125	28	73	71	77	*127*	126	139	149	166	180	182	183	271	...
43a. M'ntmellick	115	34	42	47	41	125	130	131	136	154	167	*174*	193	277	...
49a. Old Connaught	138	72	77	96	107	127	127	138	145	154	190	*193*	227	...	...
C (5)															
5a. Warminster	123	29	61	83	*69*	146	130	132	*144*	152	*175*	181	*174*	...	...
9a. Sherston .	131	49	63	100	78	121	137	142	150	152	197	196	189	250	...
1b. Ringwood .	124	29	*47*	*99*	99	118	133	135	143	*154*	169	184	175	280	...
1c. Lymington .	120	36	43	99	65	128	129	135	135	156	166	169	180	273	207
3a. Shanklin .	119	23	51	100	98	109	129	131	133	152	161	*175*	163	272	185
3b. Newport .	128	59	65	96	96	123	138	135	144	153	*164*	*188*	*171*	...	...
6a. Havant .	119	6	51	88	113	89	124	135	144	152	161	196	173	275	...
6b. Hayling Is.	126	*30*	*60*	99	105	114	134	135	139	150	190	*194*	166	267	227
7a. Botley .	122	11	*46*	88	73	123	135	137	145	154	174	*182*	197	288	230
7b. West Meon	133	43	*61*	96	105	127	137	143	154	154	185	*198*	188	271	...
11a. Petersfield .	133	52	65	108	118	*124*	135	140	143	158	157	202	192	280	224

* Observed at Bude.

† Mean of the 3 stations A 13b, c, d.

TABLE III.—DATE (DAY OF YEAR) OF FIRST FLOWERING OF PLANTS, 1922—*continued.*

STATION.	Mean Value excluding Ivy and Scabious.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Ivy.	Devil's-Bit Scabious.
16a. Fleet . .	129	49	68	89	112	116	140	138	153	157	159	203	163	283	208
6c. Chichester .	121	16	62	101	84	106	120	131	147	156	156	196	181	278	238
10a. Littleh'ton .	117	5	33	69	111	119	137	117	143	175	*153*	172	171	294	...
10b. Hove. .	125	*20*	62	*98*	101	121	136	139	142	*175*	160	175	172	252	219
15a. Devil'sDyke	111	*10*	39	51	64	100	126	122	134	152	154	197	178	260	191
15b. Horsham .	123	37	*53*	69	70	119	134	132	143	155	164	215	186	270	216
18a. Lewes .	124	*39*	55	99	77	124	133	137	140	154	159	182	*194*	...	239
18b. Hellingly .	123	20	52	59	83	114	136	138	145	150	164	233	178	293	...
18c. Ditchling .	123	29	49	91	98	133	123	130	133	152	164	196	*182*	...	...
16b. Farnham .	121	20	59	82	100	107	129	*135*	140	*154*	156	183	*188*	...	...
19a. Cranleigh .	136	*51*	*78*	*98*	115	128	135	137	140	155	*180*	*221*	192	265	...
22a. Lingfield .	127	43	*42*	78	113	130	140	145	152	156	158	197	176	295	222
22b. Warling'm .	120	8	22	85	111	126	137	138	146	148	171	173	173	255	220
22c. Purley .	131	29	52	103	104	126	130	141	151	151	200	193	193	...	...
22d. Hayes .	124	41	60	113	*109*	131	132	140	151	*151*	*187*	*185*	*185*	...	...
25a. Maidstone .	118	29	*35*	80	104	106	132	137	144	152	158	*168*	176	258	225
26a/b. Bromley .	125	55	54	107	110	128	122	127	148	152	162	*165*	172	...	...
D (4)															
3a. Lydney Pk.	126	-3	76	96	110	120	138	139	*150*	155	159	187	180	291	...
5a. Cirencester.	126	12	99	112	75	127	141	125	147	*149*	*156*	*190*	*179*	...	...
6a. Dymock .	103	*8*	49	*87*	80	87	106	108	120	122	133	*173*	159	212	...
4a. Weobley .	116	8	39	103	86	118	131	130	145	130	159	159	188	245	...
4b. Staunton .	124	18	56	82	97	117	129	142	150	157	166	198	174	258	183
6c. Kimbolton .	134	40	77	107	121	124	131	138	153	155	166	202	200	...	...
10a. W. Malvern	119	35	45	82	92	115	134	124	148	*147*	144	187	*174*	217	197
10b. Evesham .	122	*28*	*42*	*91*	121	116	129	131	146	153	*152*	*188*	170	...	...
11a. Tenbury .	127	28	46	107	117	119	137	137	148	152	165	194	173	284	196
16c. Barnt Green	133	*39*	*53*	115	127	127	140	142	153	154	*162*	*198*	*181*	...	...
10c. Ashorne .	131	26	90	104	111	121	140	140	149	158	*155*	*194*	*179*	...	...
15a. Whernalls .	126	38	77	106	74	113	133	129	*141*	*154*	*164*	*183*	*178*	...	...
15b. Stratford-on-Avon	130	*32*	78	119	103	120	135	135	*145*	152	*168*	*186*	*183*	275	217
16d. Quinton .	133	42	48	109	114	130	139	140	148	170	176	185	198	279	226
21a. Rowington .	124	*17*	*40*	*98*	*106*	122	128	135	141	153	191	186	171	...	194
21b. Birmingh'm	134	14	55	110	119	134	140	144	*150*	165	191	*191*	201	266	196
21c. Nether Whitacre	131	90	90	106	106	141	135	120	138	150	150	*165*	*175*	...	...
17a. Edgmond .	124	7	42	*71*	69	129	140	142	150	155	181	197	201	276	...
14b. Oxford .	121	13	67	104	82	114	131	136	137	150	165	*177*	175	260	...
20a. Farnborough	130	10	64	104	101	126	136	138	149	155	176	196	200	264	...
19a. W. Turville	131	*33*	*62*	113	78	120	140	139	146	153	192	*199*	*199*	...	...
24a. Bletchley .	113	32	35	63	66	*86*	100	129	*142*	152	178	187	185	248	...
24b. Nor'ampton	121	33	58	*83*	69	118	142	141	142	155	156	183	172	247	...
32a. Oundle .	128	56	65	98	67	121	140	141	156	154	*170*	*188*	185	282	...
26a. Lichfield .	140	50	71	121	113	*141*	140	142	155	159	187	185	214	...	...
30a. Ashbourne .	127	43	57	79	113	130	134	137	153	155	169	171	179	...	...
35a. Somersal Herbert	144	*54*	104	103	125	137	140	146	162	156	196	200	201	276	204
35b. Matlock .	128	28	41	100	90	115	143	145	152	158	181	184	196	261	205
38a. Hodsock .	132	48	58	109	107	127	132	140	152	155	192	194	175	267	...
39b. Kirkheaton.	142	57	75	*115*	124	*138*	145	147	160	174	199	183	192	...	...
41c. Grindleton .	144	54	73	105	128	129	149	150	160	172	185	215	214	298	...
41d. Crosshills .	135	49	45	107	111	134	145	143	155	164	173	197	*193*	273	...

TABLE III.—Date (Day of Year) of First Flowering of Plants, 1922—*continued*.

Station.	Mean Value excluding Ivy and Scabious.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Ivy.	Devil's-Bit Scabious.
45a. Middlestown	137	53	56	108	116	*128*	149	143	152	161	177	206	201	276	...
45b. Altofts	129	35	40	*94*	*108*	114	141	138	163	*157*	170	189	199	...	...
48a. Goole	135	51	59	*99*	113	137	142	140	154	157	182	*196*	193	264	...
49b. Ferrybridge	137	51	70	99	113	132	*146*	143	*158*	160	169	*197*	*201*	265	221
E (3)															
1a. Harrow	128	26	69	109	104	*131*	135	134	152	152	172	*191*	161	...	...
1b. New Barnet	122	28	54	109	87	118	125	131	145	146	157	*188*	177	...	225
2a. Berkhamst'd	128	39	61	103	99	121	141	146	148	156	161	189	170	299	...
2b. Tring	127	48	32	116	96	135	131	142	147	150	170	188	164	...	...
4b. Harpenden	*129*	49	*82*	*100*	77	120	136	136	149	152	174	*187*	191	291	...
4c. Harpenden	*131*	56	79	96	108	118	140	140	148	155	161	195	178	294	...
4d. Tewin	123	27	94	115	80	107	133	130	144	148	157	171	171	239	...
4e. Knebworth	119	49	63	83	71	*112*	136	135	141	158	*159*	158	165	...	...
4h. Hitchin	131	49	58	119	104	122	137	139	146	147	179	188	190	266	...
7a. Birch Green	128	*42*	*65*	102	113	116	139	137	143	146	171	181	181	...	...
7b. Sawb'worth	133	33	71	*110*	112	114	140	*141*	151	157	*180*	*197*	187	...	...
7c. Braughing	129	*45*	91	105	81	115	140	131	144	149	176	199	176	267	212
7d. Buntingford	121	51	75	107	75	*100*	120	116	*135*	*141*	*165*	*186*	176	...	...
7e. Stanstead Abbotts	133	43	*67*	106	112	130	138	143	168	150	168	*198*	170	277	...
8a/c. Letchw'rth	124	1	42	104	111	124	132	134	146	155	162	193	179	271	...
10a. Maldon	125	*35*	*70*	106	104	106	137	130	149	148	*163*	*189*	*164*	...	...
10b. Halstead	120	4	69	89	82	*113*	134	134	148	155	*160*	184	*165*	286	...
13a. Lexden	126	34	68	122	86	120	132	136	147	152	158	186	166	...	...
14a. Ballingdon	128	*26*	67	81	115	106	142	141	149	151	188	*192*	*173*	...	...
11a. Cambridge	121	40	76	*84*	66	113	131	137	148	153	163	188	*152*	...	...
16a. Thorney	120	10	60	*85*	72	114	138	135	144	*155*	163	*193*	167	...	...
23a. Bungay	125	20	42	70	90	106	132	136	160	*159*	190	200	196	290	186
24a. Norwich	136	*50*	*67*	104	120	127	140	138	151	156	*193*	*203*	181	270	...
25a. Hunstanton	132	*39*	74	*91*	*115*	120	140	137	153	157	170	213	171	244	...
27b. Holt	136	64	78	*94*	*112*	124	142	143	149	159	181	189	*195*	265	...
28a. Brunstead	132	52	*71*	*87*	120	109	*136*	141	151	157	188	191	187	...	...
F (7)															
9a. Beaumaris	126	30	56	75	60	126	124	145	148	171	188	202	182	264	...
11a. St. Asaph	138	30	63	103	102	126	144	146	154	170	*207*	*211*	*201*	...	...
13a. Birkenhead	131	27	57	93	109	123	137	141	*163*	161	196	185	*186*	...	...
13c. Higher Tranmere	126	11	29	*82*	103	128	131	*135*	*147*	156	203	196	196	277	...
14a. Barnton	132	34	12	89	92	140	171	141	176	161	187	209	172	275	...
17a. Leigh	134	*28*	46	*87*	*84*	*128*	144	140	149	186	197	230	*188*	...	215
21a. Leyland	140	40	54	103	*94*	*135*	142	147	164	170	*190*	222	222	300	242
22a. Urswick	139	40	59	96	110	*144*	146	147	156	157	208	195	207	268	245
25b. Ambleside	127	30	60	87	61	128	142	141	154	161	*182*	177	*197*	...	...
28a. Keswick	138	*54*	*78*	113	107	129	142	143	159	155	*212*	190	174	...	...
G (9)															
35b. Rostrevor	134	41	60	88	79	*120*	134	136	151	166	221	*225*	193	285	226
35c. Warrenpoint	131	39	51	92	73	109	139	140	151	163	210	215	188	285	...
50a. Hillsborough	144	*45*	57	98	112	*120*	140	147	161	175	218	*226*	234	291	...
50b. Comber	138	57	63	*100*	69	*119*	141	144	162	162	196	*225*	*216*	...	...

TABLE III.—DATE (DAY OF YEAR) OF FIRST FLOWERING OF PLANTS, 1922—*continued.*

STATION.	Mean Value excluding Ivy and Scabious.	Hazel.	Coltsfoot.	Wood Anemone.	Blackthorn.	Garlic Hedge-Mustard.	Horse-Chestnut.	Hawthorn.	White Ox-Eye.	Dog Rose.	Black Knapweed.	Harebell.	Greater Bindweed.	Ivy.	Devil's-Bit Scabious.
53a. Bangor .	139	57	62	99	99	*115*	135	133	160	168	208	*220*	210	...	...
48a. Altnafoyle .	146	44	51	*109*	108	*130*	142	148	*166*	188	217	*231*	*217*	...	225
51a. Magherafelt	136	45	60	99	99	*126*	126	141	152	154	201	222	*205*	269	...
50c. Belfast .	126	*38*	41	71	79	128	130	130	*151*	172	188	*190*	191	...	...
51b. Cullybackey	133	*46*	78	90	114	*120*	141	124	154	163	163	222	*180*	299	200
54a. Hazelbank .	133	58	54	86	86	*132*	*137*	140	163	171	178	193	197	204	212
55a. Ballymoney.	136	37	43	110	102	*136*	142	140	157	160	211	197	196	307	193
H (6)															
1a. Kirkmaiden	140	47	38	99	118	*133*	147	147	165	168	*211*	206	200	269	...
6a. CastleDoug.	139	54	*50*	110	107	*128*	149	154	160	161	*205*	*192*	*204*	...	...
12a. Moniaive .	142	63	*48*	99	120	*136*	*153*	154	157	*164*	*207*	*198*	*201*	...	196
I (2)															
10a. West Keal .	134	55	78	*82*	125	127	138	143	*160*	159	*168*	*183*	*195*	264	...
10b. Hagworthingham	132	*50*	*62*	110	*116*	117	140	142	149	158	*169*	173	194	...	...
11a. Cleethorpes.	131	55	59	105	120	127	139	142	147	151	175	*187*	163	273	...
11b. Thornton Abbey	134	*47*	65	*100*	98	134	144	144	*150*	161	*176*	210	*176*	...	...
12a. Howd'shire.	139	60	79	116	125	135	140	145	152	170	176	*191*	*181*	259	...
21a. Hull . .	119	26	44	42	89	116	130	121	159	162	172	180	183	270	...
23a. Thirsk .	124	8	53	99	107	116	140	141	152	156	172	175	*176*	288	189
29a. Scarborough	132	29	53	98	121	127	*145*	*145*	158	165	171	*173*	*196*	304	...
32a. Acklam .	127	38	52	88	88	139	139	139	155	160	160	160	205	...	...
33a. Lanchester.	137	55	54	111	124	125	147	147	155	160	191	169	*210*	276	226
25a. Corbridge .	145	46	65	109	126	144	148	150	158	172	209	195	*218*	...	...
J (1)															
2a. Broughton .	149	61	61	121	140	*145*	148	150	162	170	218	191	*220*	...	200
6a. Galashiels .	144	57	65	121	128	137	147	147	162	162	*200*	*186*	*212*	291	197
10a. W. Foulden	147	68	*61*	108	130	140	144	158	170	*175*	197	*196*	*218*	...	230
18a. Kinglassie .	154	*87*	84	132	*144*	145	154	152	*167*	171	*199*	*192*	*216*	287	...
16a. Callander .	145	54	59	92	120	*130*	154	161	*174*	*177*	*203*	*199*	*223*	...	...
20a. TummelB'ge	155	59	95	122	*143*	*149*	158	158	*175*	*178*	*204*	*199*	*224*	...	...
21a. Dundee .	144	54	63	125	144	*145*	144	147	161	161	*192*	184	*211*	...	215
35a. Banchory .	141	*46*	*53*	94	131	*130*	152	151	*166*	171	*195*	*191*	*215*	...	...
K (0)															
24a. Kiltarlity .	149	77	91	94	110	*115*	117	161	*187*	199	*217*	201	218	*215*	*281*
Total records used	1986	151	152	153	177	143	181	189	156	166	130	97	116	113	62

MIGRANTS (Table VII.).

The 49 stations available in 1920 and 60 of 1921 rose to 88. Compared with our 9 years' average, the 4 arrivals up to April 16 were a day late; the next 7, to April 23, 2½ days early; then 14, to May 9, were as much late, the last 3 again tending to be early. Only cuckoo and house-martin were more than 3 days early, but 4 of the

TABLE IIIA.—ADDITIONAL FLOWER RECORDS (District Means of 2 or more).

DISTRICT.	Snowdrop (*G. nivalis*).	Yel. Aconite (*E. hiemalis*).	Yel. Crocus (*C. aureus*).	Celandine (*R. ficaria*).	Mean.
A (8) England S.W.	20	16	32	42	27·5
B (10) Ireland S.	13	(8)	28	42	22·7
C (5) England S.E.	26	26	35	52	34·7
D (4) Midlands	25	20	40	64	37·2
E (3) England E.	26	26	43	58	38·2
F (7) ,, N.W.	29	27	49	63	42·0
G (9) Ireland N.	18	12	32	39	25·2
I (2) England N.E.	34	23	53	70	45·0
J (1) Scotland E.	44	(38)	65	86	58·2
Records used	139	73	116	143	(471)
Mean of all	26·1	21·8	41·9	57·3	36·8
Month and Day	J. 26	J. 22	F. 11	F. 26	F. 6
Average, 10 years, 1913–22	18·7	20·0	32·9	47·3	29·7
Month and Day	J. 19	J. 20	F. 2	F. 16	J. 30

The bracketed figures for aconite in Districts B and J have been interpolated.

early May arrivals were as much late, the lesser whitethroat by 6½ days. The 9 years' average, like the 8, is 5⅓ days behind the 20 years' average (1877–96) of the *Natural History Journal*. The main phenological value of Table VII. lies in its giving the results of sudden and short meteorological changes, obscured by the more sluggish response of plants.

ADDITIONAL SPRING MIGRANTS.—Ring-ouzel (10 records), 107 (April 17); pied flycatcher (18), 122·8 (May 3). The larger number and observers' notes indicate a wider spread for these birds. Frequent reports of the cuckoo in March appeared in the papers, some well substantiated.

OTHER MIGRANT MOVEMENTS.—Table VII.A rests on 616 records, or 35 per cent over 1921, greatly increasing its reliability. District means are therefore now added for the completer records.

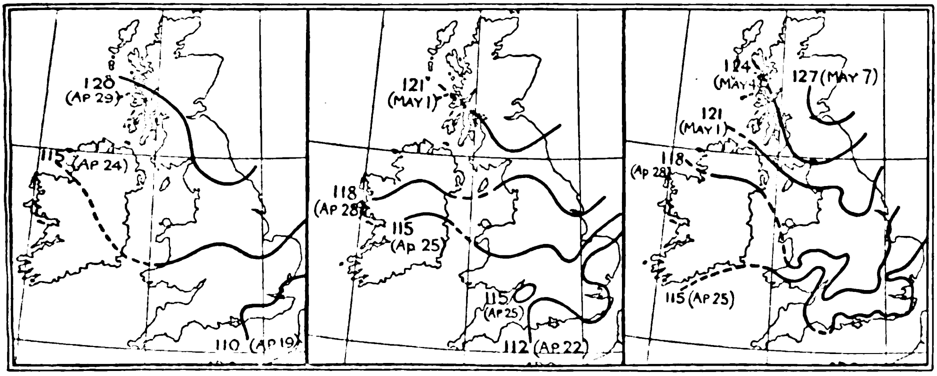
MIGRANT ISOPHENES (Lines of equal arrival dates).—These, as drawn for the third year (Fig. 4), depend on 88 stations, thus forming a fairly satisfactory basis for general results. The mean dates of the 28 birds in Table VII. range from 111 (April 21) at Devil's Dyke, Sussex, and 111½ in Guernsey, to 127 at Kinglassie, Fife, one of the two stations beyond the Forth with 9 records. Isophene 112 must be confined to the Channel Isles; 115 largely replaces its course in 1921, but embraces less of E. Anglia, and passes out to sea in E. Dorset, to reappear at the Exe and include Pembroke and part of Carmarthen. Last year 118 kept near lat. 54°, but in 1922, though again starting near the Humber, it proceeds almost due south to the east of Bedford, curves gradually westwards to the Mendips, then bends sharply N.E. past Bristol and along the Cotswolds, round Warwick in the Avon valley, and so across the Severn basin to Montgomery and south of Devil's Bridge to near Aberystwyth. The few Irish stations indicate its reappearance much farther north in Co. Down. The correspondence between this curve, floral isophene 124, and isotherm 48°·5 (had that been drawn in) is significant.

OF THE 30 YEARS 1891-1920.

PLANTS.	**A (8)** England, S.W. 1922.	Average 30 years.	Difference from 30-year Average.	**B (10)** Ireland, S. 1922.	Average 30 years.	Difference from 30-year Average.	**C (5)** England, S.E. 1922.	Average 30 years.	Difference from 30-year Average.	**D (4)** England, Mid. 1922.	Average 30 years.	Difference from 30-year Average.	**E (3)** England, E. 1922.	Average 30 years.	Difference from 30-year Average.	**F (7)** England, N.W. 1922.	Average 30 years.	Difference from 30-year Average.
Hazel (*Corylus avellana*)	31	39	− 8	46	32	+14	32	33	− 1	37	42	− 5	38	36	+ 2	33	43	−10
Coltsfoot (*Tussilago farfara*)	60	55	+ 5	64	59	+ 5	55	60	− 5	63	64	− 1	65	62	+ 3	49	64	−15
Wood Anemone (*Anemone nemorosa*)	94	85	+ 9	62	79	−17	90	82	+ 8	103	90	+13	100	88	+12	97	91	+ 6
Blackthorn (*Prunus spinosa*)	83	91	− 8	68	83	−15	97	94	+ 3	103	100	+ 3	96	97	− 1	97	102	− 5
Garlic Hedge-Mustard (*Sisymbrium alliaria*)	121	107	+14	126	113	+13	118	110	+ 8	122	113	+ 9	118	112	+ 6	129	122	+ 7
Horse-Chestnut (*Æsculus hippocastanum*)	133	122	+11	128	123	+ 5	132	126	+ 6	136	130	+ 6	136	126	+10	143	132	+11
Hawthorn (*Cratægus oxyacantha*)	135	130	+ 5	137	131	+ 6	135	131	+ 4	138	134	+ 4	136	131	+ 5	144	138	+ 6
White Ox-Eye (*Chrysanthemum leucanthemum*)	157	145	+12	146	144	+ 2	144	141	+ 3	150	148	+ 2	148	145	+ 3	159	153	+ 6
Dog Rose (*Rosa canina*)	155	155	0	162	158	+ 4	154	155	− 1	156	158	− 2	152	156	− 4	166	162	+ 4
Black Knapweed (*Centaurea nigra*)	167	172	− 5	187	183	+ 4	167	171	− 4	174	177	− 3	170	177	− 7	196	189	+ 7
Harebell (*Campanula rotundifolia*)	192	193	− 1	*185*	184	+ *1*	192	185	+ 7	190	190	0	188	189	− 1	200	187	+ 3
Greater Bindweed (*Convolvulus sepium*)	179	187	− 8	208	192	+16	179	187	− 8	188	191	− 3	177	191	−14	192	195	− 3
Ivy (*Hedera helix*)	270	263	+ 7	275	262	+13	273	269	+ 4	263	268	− 5	274	265	+ 9	277	277	0
Devil's-Bit Scabious (*Scabiosa succisa*)	222	...	...	230	...	...	218	...	...	204	...	...	208	...	...	234	...	...
Mean of the 13 Plants (excluding Scabious)	137	134	+ 3	138	134	+ 4	136	134	+ 2	140	139	+ 1	138	137	+ 1	145	143	+ 2
Mean of the 14 Plants (including Scabious)	143	...	...	145	...	...	142	...	...	145	...	...	143	...	...	151	...	...

PLANTS.	**G (9)** Ireland, N.			**H (6)** Scotland, W.			**I (2)** England, N.E.			**J (1)** Scotland, E.			**K (0)** Scotland, N.			England and Wales.*			British Isles.		
Hazel	47	49	− 2	55	47	+ 8	38	48	−10	59	55	+ 4	*77*	48	+*29*	35	40	− 5	45	44	+ 1
Coltsfoot	56	69	−13	*45*	69	−*14*	60	66	− 6	69	73	− 4	*91*	74	+*17*	59	62	− 3	62	65	− 3
Wood Anemone	92	88	+ 4	105	97	+ 8	98	93	+ 5	115	104	+11	*94*	107	−*13*	97	88	+ 9	95	92	+ 3
Blackthorn	93	101	− 8	117	114	+ 3	113	108	+ 5	131	116	+15	*110*	115	− *5*	98	98	0	101	102	− 1
Garlic Hedge-Mustard	118	110	+ 8	*132*	127	+ *5*	128	121	+ 7	141	128	+13	*115*	128	−*13*	123	114	+ 9	124	120	+ 4
Horse-Chestnut	137	131	+ 6	148	142	+ 6	141	139	+ 2	150	145	+ 5	*117*	143	−*26*	137	129	+ 8	136	133	+ 3
Hawthorn	137	138	− 1	152	145	+ 7	141	140	+ 1	151	148	+ 3	*161*	152	+ *9*	138	134	+ 4	142	139	+ 3
White Ox-Eye	157	155	+ 2	161	160	+ 1	155	158	− 3	164	163	+ 1	*187*	166	+*21*	152	148	+ 4	157	154	+ 3
Dog Rose	167	165	+ 2	165	166	− 1	161	168	− 7	167	169	− 2	*199*	167	+*32*	157	159	− 2	164	163	+ 1
Black Knapweed	200	198	+ 2	*208*	199	+ *9*	178	193	−15	207	197	+10	*217*	203	+*14*	175	180	− 5	188	190	− 2
Harebell	212	194	+18	*199*	193	+ *6*	180	191	−11	*192*	195	− *3*	*201*	197	+ *4*	190	189	+ 1	194	192	+ 2
Greater Bindweed	201	204	− 3	*202*	198	+ *4*	186	199	−13	*217*	206	+*11*	*218*	200	+*18*	183	191	− 8	195	198	− 3
Ivy	277	276	+ 1	*269*	277	− *9*	276	280	− 4	289	289	0	*281*	290	− *9*	272	270	+ 2	275	276	− 1
Devil's-Bit Scabious	214	...	...	*214*	...	...	207	...	...	215	...	...	*215*	...	...	215	...	...	216	...	...
Mean of the 13 Plants	146	144	+ 2	151	149	+ 2	143	146	− 3	158	153	+ 5	*159*	153	+ *6*	140	139	+ 1	144½	143½	+ 1

Five returns show that the early inrush over E. Anglia, marked last year by migrant isophene 112, is repeated by 115, which reaches beyond Cambridge and Hitchin. Only 10 miles here intervene between 115 and 118, though expanded elsewhere to 50 and even 70 miles. 115 cannot be traced over Ireland, and may even lie to its south. The very few records for Ireland S. indicate a mean date 5 days behind England S.W., which has a mean date of 116 (April 26). The interpretation is suggested that the keen end-of-April weather over central England held back or silenced the migrants, but that, arriving rather later in Ireland, they then spread more rapidly in consequence. There was no advantage in temperature.



1920, 49 Stations. 1921, 60 Stations. 1922, 88 Stations.

FIG. 4.—Migrant Isophenes (lines of equal arrival dates), 1920, 1921, 1922. Based on the 28 birds of the Migrant Table. See Table VII.

TABLE V.—MEAN DATES OF FLOWERING, WITH THEIR VARIATIONS FROM THE 30 YEARS' AVERAGE (1891–1920), FOR THE THIRTEEN PLANTS IN THOSE DISTRICTS WHERE THERE HAVE BEEN SUFFICIENT OBSERVATIONS TO WARRANT COMPARISONS BEING MADE. ALSO, TOTAL NUMBER OF STATIONS IN ALL ELEVEN DISTRICTS.

YEARS.	No. of Stations.	A, Eng. S.W.		C, Eng. S.E.		D, Eng. Mid.		E, Eng. E.		F, Eng. N.W.		Mean Variation from Average for the 5 Districts.
		Day of Year.	Variation from Average.	Day of Year.	Variation from Average.	Day of Year.	Variation from Average.	Day of Year.	Variation from Average.	Day of Year.	Variation from Average.	
			Days.		Days.		Days.		Days.		Days.	Days.
Latest 1891	105	144	+10	144	+10	150	+11	147	+10	150	+ 7	+ 9·6
Earliest 1893	117	118	−16	122	−12	125	−14	123	−14	128	−15	−14·2
1920†	212	126	− 8	123	−11	131	− 8	129	− 8	137	− 6	− 8·2
1921	205	125	− 9	120	−14	127	−12	125	−12	133	−10	−11·4
1922	239	137	+ 3	136	+ 2	140	+ 1	138	+ 1	145	+ 2	+ 1·8
Mean 1891–1920	...	134 May 14	...	134 May 14	...	139 May 19	...	137 May 17	...	143 May 23	...	[137·4] [May 17]

† Leap year. Allow for one day after February 28.

TABLE VI.—DATE (DAY OF YEAR) OF SONG AND MIGRATION OF BIRDS, AND FIRST APPEARANCE OF INSECTS, 1922.

Song-Thrush (*Turdus musicus*) first heard ; Swallow (*Hirundo rustica*) first seen ; Cuckoo (*Cuculus canorus*) first heard ; Nightingale (*Daulias luscinia*) first heard ; Flycatcher (*Muscicapa grisola*) first seen ; Swallow (*Hirundo rustica*) last seen ; Honey-Bee (*Apis mellifica*) ; Wasp (*Vespa vulgaris*) ; Small White Butterfly (*Pieris rapæ*) ; Orange-Tip Butterfly (*Anthocaris cardamines*) ; Meadow-Brown Butterfly (*Epinephile janira*) ; Humble Bee (*Bombus lapidarius*) first seen.

STATION.	Song-Thrush first heard.	Migration.					Insects.					
		Swallow first seen.	Cuckoo first heard.	Nightingale first heard.	Flycatcher first seen.	Swallow last seen.	Honey-Bee at flowers.	Queen Wasp on wing in open.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
A (8)												
2a. The Lizard . .	...	117	126	...	...	269	...	...	...	...	...	...
2b. Camborne . .	7	122	111	...	...	253	*111*	121	96	...	136	98
5a/b. Polperro . .	3	102	126	...	129	...	...	...	139	127	160	109
6a. Duloe . .	6	95	101	...	131	306	68	...	...	127	...	68
9a. Launceston . .	11	104	119	...	...	...	56	...	124	127	...	...
9b. Hexworthy . .	19	104	119	...	...	...	...	111	*82*	...	...	...
9c. Clawton . .	7	115	119	...	126	...	76	...	127	...	...	...
13a. Exmouth . .	17	104	107	...	125	295	56	102	105	124	140	99
13c/d. Exeter . .	1	96	107	130	130	312	42	62	126	98	112	52
18a. Weymouth . .	...	107	118	...	131	...	...	99	126	128	173	...
21a. Winfrith . .	...	103	119	127	130	287	26	111	110	127	178	109
18c. Hilton . .	...	104	107	...	143	...	68	128	...	...	...	...
21b. Corfe Castle .	19	107	116	...	...	299	*118*	128	119	129	...	124
22a. Pulham . .	12	104	...	...	...	294	...	...	...	111	...	...
24a. Blandford . .	35	104	104	111	127	280	46	98	126	199	*219*	71
24b. Edmondsham .	2	104	105	118	143	272	...	74	126	131	154	74
24d. West Melbury .	23	107	110	...	...	...	56	54	...	...	...	...
24e. Verwood . .	8	97	103	116	132	286	48	109	110	129	161	70
19a. Bradford . .	1	101	108	123	124	259	76	70	98	120	126	100
19b. Langport . .	10	113	104	127	...	247	71	...	125	128	...	130
23a. Winscombe . .	2	105	111	...	131	259	...	119	118	130	157	70
25a. Wrington . .	...	105	103	...	...	...	...	...	127	142	141	101
27a/b. Weston nr. Bath	18	113	103	120	127	...	28	110	120	134	144	126
27c. Portishead . .	4	104	104	124	...	286	61	111	125	142	134	68
29b. Pontypridd . .	23	120	121	...	...	*212*	82	120	...	...	...	...
36a. Llandilo . .	2	107	107	...	...	...	...	...	...	...	...	77
43a. Hafod . .	46	126	122	...	136	301	71	127	126	126	163	118
B (10)												
14a. Monkstown .	7	107	...	...	...	...	67	107	125	128	133	139
14b. Passage West .	1	114	134	...	...	283	...	130	128	...	133	147
22a. Lismore . .	...	105	121	...	130	...	...	...	...	...	..	...
30a. Cashel . .	5	119	121	...	133	262	*129*	131	127	135	128	89
41a. Ferns . . .	3	108	110	...	...	272	78	83	*88*	*92*	*95*	...
43a. Mountmellick .	4	105	119	...	137	264	54	128	127	128	156	108
49a. Old Connaught .	11	107	119	...	...	260	...	...	125	131	168	119
50a. Johnstown Bridge	...	108	121	...	...	269	65	94	127	...	108	89
C (5)												
5a. Warminster .	21	99	99	121	127	302	54	56	...	...	...	...
5b. Holt . . .	1	104	104	...	133	304	...	...	...	...	...	...
5c. Bratton . .	...	104	107	...	132	284	...	...	...	...	...	...
9a. Sherston . .	29	104	109	...	139	281	61	112	111	126	151	111
1a. Bournemouth .	1	105	119	...	...	315	...	...	...	...	...	...
1b. Ringwood . .	2	97	110	119	...	283	65	...	109	129	173	...
1c. Lymington . .	8	99	104	112	135	295	52	109	110	141	...	117
1d. Totland Bay .	...	104	116	...	...	301	...	...	...	...	...	...
3a. Shanklin . .	1	104	105	117	129	301	51	83	109	119	161	79
3b. Newport . .	2	104	109	112	...	...	71	127	113	148	...	*135*
6a. Havant . .	1	98	100	120	134	291	52	10	108	133	161	56
6b. Hayling Island .	...	...	105	...	...	...	117	92	127	140	144	122

The British Isles means in Table VI. are the means of the separate Districts ; in Table VII., of the original records. Those shown in brackets represent a single record only.

The dates in *italics* in Table VI. represent rejected observations, and have not been taken into consideration when calculating the means for the Districts.

TABLE VI.—DATE (DAY OF YEAR) OF SONG AND MIGRATION OF BIRDS, AND FIRST APPEARANCE OF INSECTS, 1922—*continued.*

STATION.	Song-Thrush first heard.	Migration.					Insects.					
		Swallow first seen.	Cuckoo first heard.	Nightingale first heard.	Flycatcher first seen.	Swallow last seen.	Honey-Bee at flowers.	Queen Wasp on wing in open.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
7a. Botley	7	104	101	110	134	275	32	40	110	128	154	...
7b. West Meon	9	108	106	102	...	295	56	130	129	129	129	129
11a. Petersfield	9	103	102	106	128	300	95	109	127	129	129	77
16a. Fleet	33	121	110	...	*106*	...	115	127	119	147	154	*142*
6c. Chichester	37	103	103	127	...	308	73	127	116	147	...	71
10a. Littlehampton	1	107	104	...	...	262	49	61	95	*105*	134	100
10b. Hove	2	130	119	...	139	282	78	117	125	141	152	75
15a. Devils Dyke	1	97	108	125	131	301	100	96	124	129	152	111
15b. Horsham	10	108	98	117	*107*	279	51	...	99	120	162	75
18a. Lewes	22	104	104	104	126	294	...	...	...	141	168	...
18b. Hellingly	20	96	104	110	...	291	6	4	...	...	141	...
18c. Ditchling	30	106	104	122	129	275	47	34	111	125	153	98
16a. Wrecclesham*	24	124	107	118	...	...	...	...	...	...	...	...
16b. Farnham	21	103	102	...	...	279	36	...	...	...	...	...
19a. Cranleigh	1	106	100	110	134	...	...	...	108	...	...	...
19b. Epsom District	...	108	104	...	128	269	...	...	...	...	...	...
22a. Lingfield	...	111	107	124	143	267	110	128	128	127	169	78
22b. Warlingham	1	104	104	119	140	276	71	...	104	129	156	...
22c. Purley	19	104	104	126	...	269	56	...	128	...	183	104
22d. Hayes	22	126	103	128	...	...	56	...	...	126	...	...
24a. Lympne	15	109	113	126	...	...	...	...	127	...	...	...
25a. Maidstone	22	104	102	104	...	267	71	...	124	...	169	85
26a. Bromley Common	...	128	104	115	133	...	...	127	127	143	152	104
D (4)												
1a. Bristol	10	106	118	...	132	261	99	...	113	147	...	...
3a. Lydney Park	7	107	108	...	141	280	76	...	127	140	152	109
5a. Cirencester	22	112	118	108	...	261	114	...	...	...	...	...
5b. Cheltenham	...	110	110	...	118	...	...	...	127	141	...	...
6a. Dymock	30	107	108	...	*98*	220	32	98	...	...	...	99
3b. Ross	7	107	118	...	140	...	29	48	...	...	...	...
4a. Weobley	46	114	109	130	130	291	59	125	126	144	128	128
4b. Staunton	3	104	109	...	133	278	59	128	119	127	170	109
6b. Bromyard	12	126	104	...	...	275	...	...	127	...	...	127
6c. Kimbolton	...	104	104	...	...	...	...	127	111	127	166	145
10a. West Malvern	26	120	107	...	141	257	126	109	130	121	141	127
10b. Evesham	5	122	111	123	...	270	53	123	111	142	...	...
11a. Tenbury	1	106	107	126	132	273	56	126	119	128	181	130
16a. Hampton Lovett	...	104	109	111	133	281	...	...	...	...	...	...
16b. Wolverley	...	105	109	130	129	294	...	136	119	128	...	...
16c. Barnt Green	29	108	119	...	134	...	54	110	127	...	...	119
10c. Ashorne	12	111	115	130	...	292	34	109	125	...	...	121
15a. Whernalls	...	96	104	111	127	...	126	126	100	127	127	128
15b. Stratford-on-Avon	...	103	100	120	149	...	...	122	103	129	*194*	102
16d. Quinton	32	110	108	...	139	272	49	*168*	*153*	164	172	*177*
21a. Rowington	...	...	102	119	116	...	108	104	128	127	128	120
21b. Birmingham	10	103	107	...	...	270	...	...	119	150	...	...
21c. Nether Whitacre	*117*	98	107	*158*	118	271	91	108	112	112	137	120
17a. Edgmond	10	115	117	...	...	274	...	...	127	129	...	...
14a/b. Oxford	...	104	107	125	...	...	...	...	110	...	...	71
20a. Farnborough	10	104	105	108	128	...	76	128	126	128	167	122
19a. Weston Turville	...	104	104	...	...	273	...	...	127	...	...	...
24a. Bletchley	7	108	118	129	...	278	41	89	111	117	158	86
24b. Northampton	6	104	110	129	...	288	56	56	110	140	...	...
32a. Oundle	23	121	104	...	132	290	51	*130*	*142*	170	129	...

* Received too late for inclusion in means.

TABLE VI.—DATE (DAY OF YEAR) OF SONG AND MIGRATION OF BIRDS, AND FIRST APPEARANCE OF INSECTS, 1922—*continued.*

STATION.		Migration.					Insects.					
	Song-Thrush first heard.	Swallow first seen.	Cuckoo first heard.	Nightingale first heard.	Flycatcher first seen.	Swallow last seen.	Honey-Bee at flowers.	Queen Wasp on wing in open.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
33a. Ketton	*83*	105	119	119	121	...	71	...	127	...	...	...
26a. Lichfield	32	100	99	...	...	...	106	63	121	...	...	116
35a. Somersal Herbert	10	103	107	...	128	264	...	111	127	141	172	109
35b. Matlock	27	103	110	130	136	257	122	141	143	...	...	...
37a. Newark	28	106	117	...	...	253	63	...	129	148	178	141
38a. Hodsock	31	104	106	...	...	302	54	102	127	143	...	109
39a. Huddersfield	48	105*	106	...	...	...	...	148	140	...	...	...
39b. Kirkheaton	47	119	127	...	...	261	...	...	140	...	...	*159*
41a. Hebden Bridge	...	107	118	...	133	...	...	...	...	...	...	148
41b. Wilsden	...	105	108	...	119	...	...	...	...	...	...	...
41c. Grindleton	47	124	119	...	...	253	...	140	144	...	...	...
41d. Crosshills	12	105	119	...	131	274	56	140	140	...	...	109
44b. West Melton	48	104	104	...	148	265	110	141	120	...	...	142
45a. Middlestown	31	119	117	...	...	260	...	134	119	...	...	96
48a. Goole	1	121	115	...	...	271	...	...	...	...	...	...
49a. Castleford	...	127	127	...	...	273	...	...	...	155	...	...
49b. Ferrybridge	6	104	121	...	...	276	...	136	...	144	...	129
E (3)												
1a. Harrow	...	117	111	...	...	...	54	60	127	...	146	62
1b. New Barnet	6	104	105	112	...	...	54	54	108	136	147	...
2a. Berkhamsted	10	103	105	127	143	275	55	137	116	141	192	*148*
2b. Tring	*47*	95	96	96	130	291	*115*	115	112	144	152	...
4c. Harpenden	23	119	104	126	154	269	54	127	127	127	153	127
4d. Tewin	30	115	*89*	*89*	112	286	22	89	90	107	...	*139*
4e. Knebworth	32	127	106	101	134	278	43	127	90	133	153	78
4f. Bennington	29	109	111	...	...	289	...	...	...	...	...	...
4i. Hitchin	...	101	102	110	121	...	...	...	...	...	...	...
7a. Birch Green	...	105	99	113	...	294	65	103	128	133	*108*	101
7b. Sawbridgeworth	2	104	103	110	130	305	51	70	126	129	170	109
7c. Braughing	...	109	101	126	129	281	...	99	102	127	162	115
7d. Buntingford	9	103	106	...	108	271	101	134	122	127	148	109
7e. Stanstead Abbotts	31	106	106	108	118	273	*111*	137	129	128	144	117
† Letchworth	1	103	101	104	115	281	22	56	101	120	148	103
8d. Bedford	1	99	128	128	123	283	77	104	110	112	...	103
10a. Maldon	10	104	117	...	133	275	92	103	110	127	149	129
10b. Halstead	29	105	121	...	...	275	56	98	111	141	160	112
13a. Lexden	22	104	104	105	128	280	54	109	110	135	...	...
14a. Ballingdon	1	112	118	116	...	279	...	...	...	...	...	...
11a/b. Cambridge	...	105	104	112	120	...	54	127	111	127	155	*155*
16a. Thorney	*50*	104	114	...	...	261	87	...	...	144	...	87
23a. Bungay	10	122	124	...	152	281	90	100	100	152	136	52
25a. Hunstanton	6	104	102	124	...	286	...	...	...	...	...	69
27a. Rippon Hall	14	127	116	...	...	...	...	...	...	...	...	...
27b. Holt	2	...	...	...	134	284	51	95	124	131	190	71
28a. Brunstead	28	102	106	...	136	277	54	54	109	122	188	103
F (7)												
1a. Caersws	...	104	120	...	131	287	...	...	...	...	...	...
9a. Beaumaris	7	109	121	...	*177*	269	75	125	122	147	...	88
13a. Birkenhead	2	103	128	...	134	278	93	110	120	...	154	118
13c. Higher Tranmere	7	117	107	...	...	...	...	...	...	...	...	...
14a. Barnton	45	103	106	...	...	287	110	120	121	130	156	105
14b. Altrincham	30	104	126	...	...	...	104	107	134	...	...	...
17a. Leigh	46	118	121	...	...	251	128	...	135	...	184	...

* Observed at Gunthwaite.

† Combined records of the three stations, 8a, b, c.

TABLE VI.—Date (Day of Year) of Song and Migration of Birds, and First Appearance of Insects, 1922—*continued.*

Station.	Song-Thrush first heard.	Migration.					Insects.					
		Swallow first seen.	Cuckoo first heard.	Nightingale first heard.	Flycatcher first seen.	Swallow last seen.	Honey-Bee at flowers.	Queen Wasp on wing in open.	Small White Butterfly.	Orange-Tip Butterfly.	Meadow-Brown Butterfly.	Humble Bee.
21a. Leyland	2	105	121	...	...	275	...	...	129	...	165	...
22a. Little Urswick	32	106	120	...	...	273	73	...	108	150	151	...
22b. Ulverston	32	105	120	...	140	...	...	...	...	...	...	...
25a/b. Ambleside	8	105	121	...	128	274	44	...	128	128	...	128
28a. Keswick	...	125	129	...	137	...	110	130	145	153	...	*157*
28b. Greystoke	...	128	129	...	...	266	...	...	...	...	...	...
G (9)												
12a. Belmullet	*48*	107	132	...	...	263	...	...	99	...	192	*157*
32a. Enniskillen	6	111	122	...	134	263	...	...	...	...	...	...
41a. Bessbrook	23	107	112	...	131	276	...	73	103	127	188	138
35b. Rostrevor	23	124	138	...	...	266	41	133	118	142	195	102
35c. Warrenpoint	28	104	112	...	127	276	...	120	90	127	128	77
50a. Hillsborough	2	105	108	...	134	274	...	133	120	148	...	124
50b. Comber	3	103	122	...	133	273	92	122	120	149	182	92
48a. Altnafoyle	...	...	120	...	...	...	133	...	128	141	...	...
51a. Magherafelt	3	109	110	...	...	263	109	129	142	143	152	*154*
50c. Belfast	9	108	119	...	...	269	...	106	109	...	195	...
54a. Hazelbank	15	97	110	...	...	293	...	...	...	...	...	...
55a. Ballymoney	5	106	122	...	...	259	73	94	108	152	127	...
H (6)												
1a. Kirkmaiden	15	114	136	...	...	287	82	132	...	...	133	...
6a. Castle Douglas	34	112	120	...	181	...	60	150	109	...	*215*	76
8a. Brodick	29	112	133	...	...	245	...	...	...	...	...	89
12a. Moniaive	...	105	120	...	...	279	...	126	127	126	...	...
I (2)												
5a. Cranwell	...	104	105	134	...	272	...	105	...	137	...	...
10a. West Keal	47	105	119	...	133	306	54	129	128	141	144	109
10b. Hagworthingham	...	105	104	...	132	...	111	...	130	148	...	111
11a. Cleethorpes	25	...	100	...	...	...	118	...	120	144	...	127
11b. Thornton Abbey	50	105	110	...	134	285	...	...	127	...	...	97
12a. Howdenshire	32	103	116	...	132	281	...	126	127	...	...	106
21a. Hull	20	108	105	...	...	295	92	105	135	109	...	99
23a. Thirsk	12	105	121	...	141	270	71	127	127	158	...	...
29a. Scarborough	27	104	118	...	...	...	...	...	...	...	...	...
32a. Acklam	32	131	123	...	...	...	...	...	139	147	...	...
33a. Lanchester	48	115	121	...	141	273	67	...	129	...	...	131
25a. Corbridge	44	111	128	...	...	257	...	...	...	...	...	...
38a. Embleton	28	110	135	...	129	260	119	126	119	...	...	128
J (1)												
2a/b. Broughton	57	108	119	...	129	272	72	143	128	...	...	...
4a. Selkirk	7	105	...	...	141	...	...	...	...	...	...	...
6a. Galashiels	43	106	109	...	...	...	54	144	145	...	...	...
10a. West Foulden	31	107	127	...	146	275	30	130	131	...	176	...
18a. Kinglassie	54	105	108	...	145	254	110	...	129	...	...	...
16a. Callander	55	112	121	...	...	263	57	60	120	...	...	...
20a. Tummel Bridge	41	110	120	...	133	271	...	...	141	...	193	123
21a. Dundee	70	109	132	...	...	...	...	...	118	...	...	...
K (0)												
5a. Vallay, N. Uist	...	145	133	...	...	...	...	...	...	...	...	118
24a. Kiltarlity	55	118	128	...	...	250	43	...	108	...	...	106
Total records used	167	270	273	83	121	149	127	124	159	121	92	112

TABLE VI.—Date (Day of Year) of Song and Migration of Birds, and First Appearance of Insects 1922.—*continued*; Means and Averages.

Station.	Song-Thrush first heard. (1)	Migration.						Insects.						
		Swallow first seen. (2)	Cuckoo first heard. (3)	Nightingale first heard. (4)	Flycatcher first seen. (5)	Swallow last seen. (6)	Means of 1, 2, 3, and 5. (7)	Honey-Bee at flowers. (8)	Queen Wasp on wing in open. (9)	Small White Butterfly. (10)	Orange-Tip Butterfly. (11)	Meadow-Brown Butterfly. (12)	Humble Bee. (13)	Means 8 to 12. (14)
Mean of—														
A (8) England S.W.	12	107	112	122	131	282	90½	58	106	119	131	148	95	112½
B (10) Ireland S. .	5	109	121	...	133	267	92	66	112	126	130	138	115	114½
C (5) England S.E.	12	105	104	116	132	289	88¼	65	89	116	133	155	92	111½
D (4) Midlands .	21	109	111	122	132	271	93¼	74	115	123	136	154	118	120½
E (3) England E. .	14	107	108	114	128	280	89¼	59	99	112	130	158	97	111½
F (7) England N.W.	20	109	120	...	133	273	95½	90	120	127	139	162	113	127½
G (9) Ireland N. .	12	107	119	...	132	270	92½	90	114	114	141	170	107	126
H (6) Scotland W. .	26	110	127	...	(181)	270	101¼	71	136	118	(126)	(133)	82	(117)
I (2) England N.E.	31	107	116	(134)	133	278	97	86	120	126	141	(144)	113	123½
J (1) Scotland E. .	43	108	121	...	137	267	102¼	65	119	130	...	184	(123)	129
K (0) Scotland N. .	(55)	125	128	...	...	(250)	114¾	(43)	...	(108)	...	...	112	...
† 8 Years' Average of—														
A (8) England S.W.	12	107	113	122	136	279	92	62	102	109	128	157	...	111½
B (10) Ireland S. .	15	109	118	...	132	274	93½	65	94	113	124	143	...	107¾
C (5) England S.E.	10	108	109	117	130	286	99¼	68	93	108	127	156	...	110½
D (4) Midlands .	20	112	115	123	134	275	95¼	70	104	117	131	163	...	117
E (3) England E. .	15	112	112	120	141	284	95	63	98	108	130	170	...	113¾
F (7) England N.W.	18	111	120	...	129	283	94½	85	107	115	139	165	...	122¼
G (9) Ireland N. .	20	112	119	...	131	271	95½	82	113	117	129	154	...	119
H (6) Scotland W. .	28	114	126	...	...	283	102¾	87	124	125	...	156	...	125½
I (2) England N.E.	24	114	117	...	131	277	96½	77	112	121	141	162	...	121¼
J (1) Scotland E. .	28	116	125	...	138	276	101¾	71	114	129	...	...	...	...
Mean of British Isles, 1922 . . .	23 Jan. 23	109 Apr. 19	117 Apr. 27	127‡ May 7	137 May 17	272 Sep. 29	96½ Apr. 6	70 Mar. 11	113 Apr. 23	120 Apr. 30	134 May 14	154 June 3	106 Apr. 16	118 Apr. 28
30 years' Mean, 1891–1920 . . .	22 Jan. 22	109 Apr. 19	114 Apr. 24	122 May 2	135 May 15	283 Oct. 10	95 Apr. 5	60 Mar. 1	103 Apr. 13	111 Apr. 21	131 May 11	164 June 13	... ...	113¾ Apr. 24
1922. Difference from 30 years' Mean .	+1	0	+3	+5	+2	−11	+1½	+10	+10	+9	+3	−10	...	+4¼

Mean values in brackets indicate a single record only.

† 1915-22.

‡ The difference between the dates for the nightingale and cuckoo in those Districts in which *both* have been recorded, has been used as a basis for deriving the British Isles means for the former bird.

Passing north of the Humber, isophene 121 (May 1), starting from Scarborough, also bends southwards over south Yorkshire, then follows the Pennines northwards round the head of Morecambe Bay, and so to the north of Ireland. 124 appears to cross from Alnwick to Carlisle and Kirkcudbright, whence probably north-westward and northward to near Oban. Isophene 127 may be indicated as taking in the north-east shores of the Forth and areas north from there. Data fail entirely for Scotland north of Perthshire.

At an early date we would like to develop separate isophenes for the birds and insects of Table VI. The former were 1½ days later than the

30 years' average, the migrants half a day on the 9 years of Table VII. Insects were 4⅓ days late. The three earlier averaged 10 days, and the orange-tip 3. But the late May heat and sun brought out the meadow-brown by July 3, or 10 days early, only a day later than in 1921.

SUMMARY OF OBSERVERS' NOTES.

Several have again accompanied their records with useful tables. We regret to hear that Mr. Lowe's, which for eight years has formed our Table VIII., is likely to cease owing to change of residence. But it will have great value for retro-correlation with the work now being planned by the Ministry of Agriculture. The same reason ends the records of fifty early flowers at Asgarth, Purley. 1922 gave as mean date Feb. 12, or 24 days later than 1921, 27 than 1913, but 38 days earlier than 1917. Winter and early spring flowers naturally vary much more in date than a series taken later on.

Mr. E. G. Ingold, of Bangor, Ireland N., has sent us plant records from 11 stations in that district, based on a more extensive list than ours. These have materially assisted us in plotting the floral isophenes accurately over N.W. Ireland.

Dr. A. E. Mahood (now of Tiverton) contributes a valuable series of notes from the *Banffshire Journal* for 1922. He has also secured us for 1923 several fresh observers in that previously blank district, as well as others in Devon and S.W. Wales. Banffshire shared with other districts in the extreme early mildness. Sparrows' eggs were reported Jan. 17, when grass was as green as in April. Then came a wild week of snow, often repeated into April. Bees only got to flowers in mid-April, when first sowing began in the warmer parts, following up the melting snow on higher ground into May ; one of the latest seasons on record, 1879 and 1917 alone being comparable. The brief summer outburst from May 23 quickly carpeted the woods with primroses, anemones, violets, etc., the sloe, too, flowering. At mid-May hawthorn trees at Tomintoul were leafless, though flowering at Aberdeen. Yet by August the crops, though late, looked well, till rain and frost in the last week damaged the month-late hay. Harvest began in September, much oats being cut green, and was general by mid-October. Stooks, snowed under in early November, were finally garnered before December. Such a record deserves this special noting and serves also for other belated areas.

Many records result from the December warmth. Xerophils, as *Iris unguiculata* (*stylosa*), flowered as never before from the ripening effects of 1921.

The October weather seemed to be pre-potent in wood-ripening, both garden and wild. Many trees flowered and fruited for the first time in this country. But some herbs, as the harebell, suffered, while in parts the daisy had no winter flowers, none being seen at Purley until March 24. The cool damp of 1922 was followed by profuse winter flowering. Particular effects like this are worth noting. The luxuriance of summer flowering corms and bulbous plants (*e.g.* gladiolus, montbretia, kniphophia) also seemed due to 1921 ripening, combined with the cool summer.

Oxford notes on 90 wild flowers show a day late up to March 1, 11 days to May 20, 5 days early to July 19, and 5 late to Aug. 8. Many report similar results ; also that the effect on herbs was greater than on trees.

The mid-May to mid-June drought injured hay, oats, early potatoes, peas, turnips, etc. The sudden warmth, when vegetation was so belated, was magical. Trees were "covered with a green mist" and apples blossomed out full in a day.

TABLE VII.—Spri

STATIONS. (88 selected out of about 200 of our observers, besides over 100 from periodicals.)	Mean Value.†	Wheatear (*Saxicola œnanthe*).	Chiffchaff (*Phylloscopus rufus*).	Wryneck (*Iynx torquilla*).	Willow Warbler (*Phylloscopus trochilus*).	Swallow (*Hirundo rustica*).	Sand Martin (*Cotile riparia*).	Tree Pipit (*Anthus trivialis*).	Yellow Wagtail (*Motacilla Raii*).	Blackcap (*Sylvia atricapilla*).	Cuckoo (*Cuculus canorus*).	Nightingale (*Daulias luscinia*).
A0a. Guernsey*	111·6	85	75	93	104	105	*106*	*106*	*102*	*107*	99	117
5a. Polperro	116·7	108	75	*108*	112	102	*111*	110	*107*	*112*	126	*122*
6a. Duloe	114·9	*94*	75	*108*	108	95	*111*	110	*107*	*112*	101	*122*
13c. Exeter	114·9	*94*	99	*108*	105	96	111	*111*	*107*	111	108	130
21a. Winfrith	116·7	99	101	96	109	103	*111*	*111*	*107*	118	119	127
24a. Blandford	114·2	78	77	*108*	100	104	*111*	*111*	*107*	*112*	104	111
24d. West Melbury	115·5	107	92	*108*	112	107	*111*	*111*	107	105	110	*122*
24e. Verwood	115·1	78	102	110	103	97	104	112	105	117	103	116
23a. Winscombe	117·6	83	100	118	101	105	120	108	*107*	*112*	111	*122*
34a. Laugharne	115·0	88	89	*108*	103	101	107	111	*107*	111	119	*122*
36a. Llandilo	116·0	80	100	*108*	108	107	*111*	109	*107*	104	107	*122*
43a. Hafod	118·9	*94*	111	*108*	*103*	126	*111*	*111*	*107*	112	122	*122*
B22a. Lismore	118·8	*96*	94	*100*	108	105	*120*	*118*	*111*	*119*	121	*125*
C5a. Warminster	115·9	*97*	110	*103*	104	99	100	*106*	*110*	104	99	121
5b. Holt	116·4	*97*	92	*103*	104	104	*109*	110	117	109	104	*116*
5c. Bratton	117·0	*97*	91	*103*	104	104	106	107	*110*	118	107	*116*
9a. Sherston	120·1	105	104	*103*	104	104	116	118	112	120	109	*116*
1b. Ringwood	116·8	*97*	103	118	103	97	100	115	105	108	110	119
1c. Lymington	115·3	*97*	86	103	104	99	112	*106*	*110*	*109*	104	112
3a. Shanklin	116·0	102	86	88	100	104	100	115	*110*	102	105	117
6a. Havant	114·9	80	87	106	104	98	95	103	*110*	113	100	120
7a. Botley	115·5	*97*	84	100	106	104	*109*	*106*	*110*	106	101	110
11a. Petersfield	117·0	*97*	104	*103*	92	103	112	97	*110*	123	102	106
6c. Chichester	118·6	*97*	113	*103*	110	103	*109*	*106*	*110*	113	103	127
15a. Devil's Dyke	111·2	81	108	110	*104*	97	101	78	*110*	93	108	125
18a. Lewes	114·0	78	85	105	99	104	106	104	*110*	105	104	104
18c. Ditchling	115·4	*97*	94	103	109	106	106	110	*110*	*109*	104	122
16c. Hambledon	116·9	*97*	104	*103*	103	*105*	*109*	109	*110*	*109*	104	116
19b. Epsom District	117·2	*97*	111	*103*	104	108	*109*	*106*	*110*	104	104	*116*
22b. Warlingham	116·7	*97*	104	*103*	104	104	*109*	104	*110*	*109*	104	119
24a. Lympne	117·3	113	103	105	104	109	*109*	*106*	*110*	*109*	113	126
D1a. Bristol	120·7	*95*	105	*120*	116	106	127	116	*114*	124	118	*122*
5a. Cirencester	119·8	*95*	*104*	*120*	*108*	112	*113*	110	*114*	124	118	108
4b. Staunton-on-Arrow	118·0	*95*	92	*120*	105	104	104	*113*	*114*	114	109	*122*
10b. Evesham	122·1	*95*	110	*120*	111	122	*113*	111	*114*	*119*	111	123
11a. Tenbury	117·9	90	94	*120*	105	106	*113*	109	*114*	111	107	126
16a. Hampton Lovett	117·8	*95*	104	*120*	104	104	104	112	*114*	120	109	111
16b. Wolverley	120·7	*95*	101	*120*	108	105	*113*	108	*114*	122	109	130
16c. Barnt Green	122·0	*95*	108	*120*	107	108	127	110	*114*	*119*	119	*122*
15a. Whernalls	117·0	*95*	100	*120*	100	96	128	104	*114*	119	104	111
15b. Stratford-on-Avon	119·4	*95*	102	*120*	*108*	103	102	120	*114*	121	100	120
16d. Quinton	121·1	95	99	123	112	110	119	*113*	*114*	118	108	*122*
21a. Rowington	118·2	*95*	116	*120*	*108*	*109*	*113*	*113*	121	108	102	110
21b. Birmingham	120·4	*95*	102	*120*	105	103	*113*	127	*114*	*119*	107	*122*
17a. Edgmund	120·6	*95*	96	*120*	109	115	*113*	111	116	111	117	*122*
20a. Farnborough	117·7	*95*	103	*120*	*108*	104	*113*	*113*	*114*	125	105	108
32a. Oundle	122·6	*95*	124	*120*	128	121	121	*113*	127	104	*111*	*122*
35a. Somersal Herbert	118·9	*95*	100	*120*	105	103	109	109	105	121	107	*122*
37a. Newark	119·9	*95*	*104*	*120*	109	106	105	*113*	*114*	*119*	117	*122*
41a. Hebden Bridge	121·8	98	*104*	*121*	105	107	*113*	111	106	*120*	118	*122*
41b. Wilsden	119·2	96	*104*	*121*	105	105	106	110	105	*120*	108	*122*
41d. Crosshills	120·7	*95*	*104*	*121*	103	105	119	*114*	115	*120*	119	*122*
49b. Ferrybridge	122·0	95	*104*	*121*	113	104	122	115	110	*120*	121	*122*

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* Received too late for inclusion in means.

† The *Bird* values are the mean of al

The *Station* values are obtained by interpolating for blanks either the district mean or a considered value from

MIGRANT TABLE, 1922.

Whinchat (*Pratincola rubetra*).	Redstart (*Ruticilla phœnicurus*).	Whitethroat (*Sylvia cinerea*).	Sedge Warbler (*Acrocephalus phragmitis*).	Sandpiper (*Totanus hypoleucus*).	Reed Warbler (*Motacilla arundinacea*).	Grasshopper Warbler (*Locustella nævia*).	Lesser Whitethroat (*Sylvia curruca*).	Wood Warbler (*Phylloscopus sibilatrix*).	Corncrake (*Crex pratensis*).	Turtle Dove (*Turtur communis*).	Garden Warbler (*Sylvia hortensis*).	Swift (*Cypselus apus*).	Nightjar (*Caprimulgus europæus*).	Red-backed Shrike (*Lanius collurio*).	Spotted Flycatcher (*Muscicapa grisola*).
113	*104*	*115*	*117*	*109*	*113*	*117*	*121*	*123*	*121*	*116*	131	125	140	*129*	*126*
118	*109*	127	126	*114*	*118*	*122*	*126*	*128*	*126*	*121*	127	119	123	*134*	129
118	*109*	128	*122*	*114*	*118*	*122*	*126*	*128*	129	*121*	*123*	114	135	*134*	131
118	*109*	106	*122*	*114*	*118*	*122*	*126*	*128*	133	*121*	*123*	125	132	*134*	130
118	*109*	116	116	111	*118*	*122*	130	*128*	*126*	122	120	111	141	143	130
118	107	126	*112*	*114*	*118*	*122*	127	127	*126*	114	129	125	129	*134*	127
118	*109*	110	*122*	*114*	107	*122*	*126*	*128*	*126*	*121*	*123*	116	*135*	*134*	*131*
118	*109*	119	112	*114*	130	121	118	128	*126*	126	128	105	139	135	132
118	*109*	122	*122*	*114*	*118*	120	127	*128*	*126*	*121*	122	129	144	130	131
118	*109*	*120*	121	107	*118*	*122*	*126*	*128*	115	*121*	*123*	121	*135*	*134*	*131*
118	*109*	128	*122*	120	*118*	127	*126*	128	*126*	*121*	*123*	118	*135*	128	*131*
109	119	129	*122*	*114*	*118*	*122*	*126*	128	*126*	*121*	110	129	*135*	*134*	136
118	*114*	*130*	*129*	*118*	*120*	*123*	*124*	*127*	128	*127*	*126*	122	*129*	*136*	130
119	110	112	127	*124*	127	129	127	*126*	126	124	*122*	109	*135*	*140*	127
119	107	*113*	117	*124*	*125*	*125*	*121*	*126*	133	131	*122*	*118*	*135*	*140*	133
119	*110*	*113*	*118*	*124*	134	*125*	114	*126*	*130*	*128*	134	126	*135*	136	132
126	123	118	128	124	130	*125*	125	129	*130*	132	*122*	121	*135*	138	139
119	*110*	*113*	111	*124*	*125*	*125*	*121*	126	144	137	*122*	106	144	*140*	*132*
119	*110*	107	*118*	*124*	*125*	*125*	118	*126*	*130*	134	*122*	116	*135*	*140*	135
119	*110*	129	131	*124*	129	*125*	*121*	*126*	*130*	128	131	117	*135*	126	129
120	119	119	116	*124*	*125*	*125*	128	126	*130*	124	*122*	109	126	*140*	134
119	*110*	120	*118*	*124*	*125*	*125*	*121*	*126*	*130*	136	108	118	136	*140*	134
119	*110*	129	*118*	*124*	*125*	*125*	122	*126*	*130*	129	129	111	*135*	*140*	128
119	*110*	*113*	*118*	*124*	*125*	*125*	127	*126*	*130*	134	127	122	127	*140*	*132*
120	92	93	*118*	*124*	*125*	*125*	105	*126*	*130*	*128*	102	103	*135*	*140*	131
119	*110*	119	113	129	122	127	126	127	*130*	127	129	118	*135*	127	126
102	*110*	111	*118*	*124*	*125*	124	119	*126*	128	114	123	126	134	144	129
119	117	*113*	*118*	*124*	*125*	*125*	*121*	*126*	*130*	129	*122*	122	130	*140*	*132*
119	*110*	*113*	*118*	*124*	*125*	*125*	*121*	*126*	*130*	*128*	*122*	120	*135*	145	128
119	107	106	*118*	*124*	*125*	*125*	*121*	127	*130*	126	124	119	141	*140*	140
119	*110*	104	*118*	*124*	*125*	*125*	*121*	*126*	*130*	*128*	*122*	114	*135*	*140*	*132*
125	105	116	*128*	*113*	*129*	*120*	*125*	*126*	*131*	*132*	*129*	127	*132*	*136*	132
125	*118*	*118*	*128*	*113*	*129*	*120*	138	*126*	118	*132*	134	124	*132*	*136*	*132*
125	*118*	105	*128*	*113*	*129*	*120*	*125*	*126*	*131*	133	134	119	*132*	*136*	133
125	124	*118*	139	*113*	139	*120*	*125*	*126*	142	*132*	*129*	123	143	129	*132*
125	126	107	*128*	*113*	*129*	117	123	112	139	139	144	126	104	*136*	132
112	120	112	*128*	*113*	*129*	*120*	*125*	*126*	122	132	*129*	120	*132*	138	133
125	136	122	*128*	*113*	*129*	*120*	128	*126*	*131*	128	*129*	*124*	*132*	140	129
127	127	127	*128*	112	*129*	*120*	127	134	137	140	127	126	*132*	*136*	134
125	109	105	*128*	*113*	*129*	122	119	*126*	127	129	126	118	*132*	140	127
125	*118*	118	120	*113*	*129*	121	120	*126*	*131*	132	*129*	119	*132*	132	149
130	*118*	111	119	120	124	*120*	128	136	140	135	122	137	*132*	*136*	139
123	*118*	*118*	*128*	*113*	125	*120*	*125*	*126*	118	122	*129*	*124*	*132*	*136*	116
125	*118*	107	*128*	*113*	*129*	*120*	*125*	*126*	138	134	*129*	126	*132*	*136*	*132*
125	*118*	130	*128*	120	*129*	*120*	*125*	*126*	*131*	131	*129*	126	*132*	*136*	*132*
125	*118*	*118*	*128*	*113*	*129*	*120*	110	*126*	*131*	128	111	129	*132*	*136*	128
125	*118*	127	*128*	*113*	*129*	*120*	*125*	*126*	*131*	128	128	126	*132*	*136*	132
127	105	127	128	*113*	*129*	*120*	127	*126*	*131*	*132*	136	127	*132*	*136*	128
125	*118*	104	*128*	*113*	*129*	*120*	*125*	*126*	117	137	*129*	127	128	*136*	*132*
128	107	*122*	*129*	114	*130*	*122*	*127*	129	144	*134*	*132*	133	140	*136*	133
126	*120*	131	134	104	*130*	*122*	*127*	120	*131*	*134*	133	126	*135*	*136*	119
126	129	*122*	*129*	119	*130*	*122*	*127*	*127*	120	*134*	*132*	119	*135*	*136*	131
126	130	131	*129*	*113*	*130*	*122*	*127*	*127*	127	137	*132*	126	*135*	*136*	*132*

cords (except those abnormally early or late), without any interpolation.
cords. Such values are printed in *italics*. 91 is April 1; 101, April 11; 111, April 21; 121, May 1; 131, May 11.

TABLE VII.—SPRI

STATIONS. (88 selected out of about 200 of our observers, besides over 100 from periodicals.)	Mean Value.†	Wheatear (*Saxicola œnanthe*).	Chiffchaff (*Phylloscopus rufus*).	Wryneck (*Lynx torquilla*).	Willow Warbler (*Phylloscopus trochilus*).	Swallow (*Hirundo rustica*).	Sand Martin (*Cotile riparia*).	Tree Pipit (*Anthus trivialis*).	Yellow Wagtail (*Motacilla Raii*).	Blackcap (*Sylvia atricapilla*).	Cuckoo (*Cuculus canorus*).	Nightingale (*Daulias luscinia*).	House Martin
E 1c. Barnet	116·1	106	99	*106*	99	106	*108*	121	*113*	121	*108*	*114*	11
4e. Knebworth	117·4	*102*	*98*	112	*104*	127	*108*	*108*	127	84	106	101	10
4i. Hitchin	114·6	107	84	*106*	104	101	*108*	107	110	105	102	110	10
7b. Sawbridgeworth	115·8	*102*	101	105	104	104	106	102	103	111	103	110	11
7d. Buntingford	114·4	*102*	*98*	*106*	*104*	103	*108*	*108*	*113*	116	106	*114*	13
7e. Stanstead Abbotts	119·2	*102*	119	*106*	112	106	112	131	*113*	*109*	106	108	12
‡ Letchworth	113·4	105	85	95	103	103	103	104	132	107	101	104	10
8d. Bedford	119·2	113	97	110	94	99	117	107	98	135	128	128	117
10a. Maldon	117·4	*102*	*98*	*106*	104	104	*108*	104	128	*109*	117	*114*	12
14a. Ballingdon	117·4	*102*	97	106	104	112	*108*	103	*113*	116	118	116	11
11a/b Cambridge	113·6	*102*	92	118	101	105	106	104	107	107	104	112	10
23a. Bungay	114·5	80	73	96	112	122	110	100	108	100	124	*114*	12
F 1a. Caersws	118·3	78	78	118	109	104	104	*124*	113	134	120	*125*	11
9a. Beaumaris	121·4	107	101	*118*	96	109	119	*124*	131	*126*	121	*125*	14
13a. Birkenhead	120·1	111	*97*	*118*	101	103	108	139	107	*126*	128	*125*	12
14a. Barnton	118·6	*96*	103	*118*	100	103	103	130	118	118	106	*125*	11
17a. Leigh	119·2	*96*	*97*	*118*	*105*	118	102	*124*	118	121	121	*125*	11
22b. Ulverston	121·1	*96*	*97*	*118*	106	105	108	*124*	*115*	*126*	120	*125*	10
25a. Ambleside	118·3	96	108	*118*	108	105	*109*	118	110	124	121	*125*	10
G 32a. Enniskillen	118·7	*96*	78	*113*	103	111	106	*118*	*111*	*119*	122	*125*	11
41a. Bessbrook	118·8	*96*	82	*113*	*108*	107	127	*118*	*111*	*119*	112	*125*	11
35c. Warrenpoint	119·1	*96*	113	*113*	108	104	*114*	*118*	*111*	*119*	112	*125*	11
50a. Hillsborough	119·5	*96*	94	*113*	108	105	114	*118*	*111*	*119*	108	*125*	11
50b. Comber	118·8	*96*	91	*113*	103	103	106	*118*	*111*	*119*	122	*125*	11
54a. Hazelbank	116·9	*96*	89	*113*	*108*	97	100	108	*111*	*119*	110	*125*	10
H 6a. Castle Douglas	125·7	101	*103*	*122*	108	112	*108*	*129*	*117*	*130*	120	*130*	1
I 11b. Thornton Abbey	120·6	96	*102*	*121*	103	105	*111*	*124*	112	134	110	*130*	10
12a. Howdenshire	120·4	99	103	*121*	103	103	103	119	*110*	*129*	116	*130*	12
14a. York	114·2	107	76	*121*	76	*107*	104	104	76	106	107	*130*	10
21a. Hull	120·6	99	104	*121*	109	108	*111*	*124*	*110*	123	105	*130*	11
29a. Scarborough	121·0	108	104	*121*	104	104	*111*	*124*	115	*129*	118	*130*	10
38a. Embleton	124·5	98	111	*121*	110	110	*111*	*124*	*110*	140	135	*130*	11
J 2b. Broughton	126·3	97	*103*	*122*	105	108	113	*129*	*117*	*130*	121	*130*	13
18a. Kinglassie	127·4	*98*	*103*	*122*	119	105	119	*129*	*117*	*130*	108	*130*	12
20a. Tummel Bridge	125·6	99	*103*	*122*	111	110	113	117	*117*	*130*	120	*130*	13
Total records used = 2263	...	68	137	31	134	270	76	67	44	76	273	83	11
Mean of—													
A (8) England S.W.	...	94	96	108	103	107	111	111	106	112	112	122	11
C (5) England S.E.	...	97	101	103	104	105	109	106	110	109	104	116	11
D (4) Midlands	...	95	104	(123)	108	109	113	113	114	119	111	122	11
E (3) England E.	...	102	98	106	104	107	108	108	113	109	108	114	11
F (7) England N.W.	...	94	97	(118)	105	109	109	127	115	126	120	...	11
G (9) Ireland N.	...	(99)	92	...	108	107	114	(108)	...	...	119	...	11
I (2) England N.E.	...	101	102	...	103	107	111	124	110	129	116	(134)	11
J (1) Scotland E.	...	98	...	...	110	108	115	129	(117)	...	121	...	12
Mean, 1922	118·2	97·2	99·4	105·9	105·2	107·5	111·3	111·6	112·6	114·1	111·5	121·5§	11
Day of Month	A. 28	A. 7	A. 9	A. 16	A. 15	A. 17½	A. 21	A. 22	A. 23	A. 24	A. 21½	M. 1½	A.
Mean 9 yrs., 1914–22	117·6	97·4	97·3	103·9	105·6	110·3	111·6	113·5	114·6	112·2	115·4	119·3§	11
,, N.H.J., 1877–96	112·3	93	94	102	103	104	106	107	109	110	110	111	11
Diff. from 9 years' mean	+0·6	0	+2	+2	−½	−3	−½	−2	−2	+2	−4	+2	−

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* Mean of 6 years only. † The *Bird* values are the mean of all actual records (except those abnormally early or
The *Station* values are obtained by interpolating for blanks either the district mean or a considered value from a

IGRANT TABLE, 1922—*continued.*

Whinchat (*Pratincola rubetra*).	Redstart (*Ruticilla phœnicurus*).	Whitethroat (*Sylvia cinerea*).	Sedge Warbler (*Acrocephalus phragmitis*).	Sandpiper (*Totanus hypoleucus*).	Reed Warbler. (*Motacilla arundinacea*).	Grasshopper Warbler. (*Locustella nævia*).	Lesser Whitethroat (*Sylvia curruca*).	Wood Warbler (*Phylloscopus sibilatrix*).	Corncrake (*Crex pratensis*).	Turtle Dove (*Turtur communis*).	Garden Warbler (*Sylvia hortensis*).	Swift (*Cypselus apus*).	Nightjar (*Caprimulgus europæus*).	Red-backed Shrike (*Lanius collurio*).	Spotted Flycatcher (*Muscicapa grisola*).
113	106	106	*120*	*116*	*125*	*122*	*119*	*123*	*130*	*125*	*122*	116	*133*	*133*	*128*
134	*106*	134	*120*	*116*	*125*	*122*	*119*	*123*	*130*	*125*	*122*	126	*133*	*133*	134
119	105	122	117	*116*	*125*	*122*	127	*123*	127	*125*	124	118	*133*	*133*	121
119	114	110	124	116	*125*	*122*	122	*123*	*130*	126	*122*	129	*133*	*133*	130
119	*106*	102	*120*	*116*	*125*	141	103	*123*	120	110	*122*	134	110	*133*	108
125	*106*	118	129	*116*	129	*122*	132	112	*130*	136	113	128	141	*133*	118
108	107	104	*120*	*116*	127	110	105	134	141	124	133	110	134	140	115
127	110	105	137	*116*	140	*122*	126	127	128	131	*122*	119	*133*	129	123
127	*106*	104	*120*	*116*	*125*	*122*	128	*123*	*130*	*125*	*122*	126	*133*	128	133
119	*106*	119	*120*	*116*	*125*	*122*	120	*123*	135	127	*122*	126	*133*	*133*	*128*
110	*106*	106	110	*116*	113	124	127	*123*	*130*	120	*122*	122	*133*	*133*	120
120	102	113	114	116	118	130	117	116	128	125	120	112	132	*133*	152
120	127	120	*131*	108	*121*	*120*	*119*	110	134	*134*	*128*	120	*128*	138	131
123	*118*	*118*	*131*	*110*	*121*	*120*	*119*	*120*	117	*134*	*128*	127	*128*	*129*	*133*
123	*118*	119	*131*	*110*	113	*120*	*119*	*120*	128	*134*	*128*	126	*128*	120	134
128	116	116	128	93	128	*120*	120	134	127	134	125	125	*128*	·130	*133*
123	*118*	105	*131*	*110*	121	*120*	118	*120*	140	*134*	125	121	*128*	*129*	*133*
132	*118*	123	134	134	*121*	*120*	*119*	*120*	*130*	*134*	134	127	*128*	*129*	140
114	112	127	*131*	106	*121*	*120*	*119*	117	127	*134*	127	126	*128*	*129*	128
118	*114*	147	136	*118*	*120*	*123*	*124*	*124*	106	*127*	*126*	127	*129*	*136*	134
118	*114*	118	*137*	*118*	*120*	*123*	*124*	*124*	132	*127*	*126*	119	*129*	*136*	131
118	*114*	127	*137*	*118*	*120*	*123*	*124*	*124*	119	*127*	*126*	121	124	*136*	127
118	*114*	144	146	*118*	*120*	*123*	*124*	*124*	109	*127*	*126*	126	*129*	*136*	134
118	*114*	135	130	*118*	*120*	*123*	*124*	*124*	124	*127*	*126*	125	*129*	*136*	133
110	114	*134*	*137*	*118*	*120*	115	*124*	*124*	120	125	*126*	124	*129*	*136*	*132*
97	*114*	133	*150*	*116*	*126*	*123*	131	*132*	133	*134*	*140*	*126*	*140*	*138*	181
123	*119*	121	127	*117*	*126*	*122*	127	*127*	*126*	130	134	127	*125*	*137*	134
126	*119*	112	125	*117*	*126*	*122*	129	*127*	126	147	*132*	126	108	*137*	132
120	106	*127*	120	104	*126*	120	*128*	*127*	130	122	120	121	137	*137*	*133*
123	*119*	*127*	123	*117*	124	*122*	*128*	*127*	*126*	*133*	*132*	124	*125*	*137*	*133*
123	*119*	124	129	*117*	*126*	*122*	*128*	*127*	116	*133*	*132*	124	*125*	*137*	*133*
123	114	136	144	139	*126*	*122*	*128*	127	*126*	*133*	138	*126*	*125*	*137*	129
129	135	*145*	*150*	108	*126*	*123*	*128*	*132*	133	*134*	*140*	135	*140*	*138*	130
129	*124*	149	161	132	*126*	*123*	*128*	*132*	*135*	*134*	*140*	121	*140*	*138*	145
130	114	142	145	109	*126*	*123*	*128*	138	*135*	*134*	144	127	147	*138*	133
34	47	95	41	32	20	19	44	30	78	64	44	157	33	26	121
109)	109	120	122	114	118	122	126	128	126	121	123	121	135	134	131
119	110	113	118	127	125	125	121	126	130	128	122	118	135	142	132
125	118	118	128	113	129	120	125	126	131	132	129	124	132	136	132
119	106	112	120	116	125	122	119	123	130	125	122	124	133	133	128
123	118	118	131	110	121	…	119	120	130	134	128	125	…	129	133
110)	(114)	134	137	(128)	…	(115)	…	…	120	(125)	…	125	(124)	…	132
123	117	127	127	117	(124)	(120)	128	127	126	133	132	126	118	…	133
129	124	145	153	114	…	…	…	(138)	135	…	142	126	(147)	…	137
20·3	113·1	118·3	125·5	116·0	124·3	122·1	125·5	125·8	128·0	128·6	126·2	122·8	132·4	136·6	131·9
30	A. 23	A. 28	My. 5½	A. 26	My. 4	My. 2	My. 5½	My. 6	My. 8	My. 9	My. 6	My. 3	My. 12	My. 17	My. 12
20·3	116·2	117·1	122·1	115·1	123·5*	119·1	119·1	121·7	124·3	126·9	123·6	124·0	133·0	134·4	134·2
113	112	113	115	117	…	118	118	119	121	123	125	125	129	133	128
0	− 3	+ 1	+ 3½	+ 1	+ 1	+ 3	+ 6½	+ 4	+ 3½	+ 1½	+ 2½	− 1	− ½	+ 2	− 2½

ithout any interpolation. ‡ Combination of the 3 stations 8a, b, c. § See footnote to Table VI., p. 262.
cords. Such values are printed in *italics*. 91 is April 1; 101, April 11; 111, April 21; 121, May 1; 131, May 11.

TABLE VIIa.—Additional Bird Records.

District.	First Song Missel Thrush.	First Song Blackbird.	First Song Lark.	Last Call Cuckoo.	Last Swift.	Last House Martin.	Last Sand Martin.	First Fieldfare.	First Redwing.
A (8) England S.W.	16	43	34	177	225	284	(269)	322	302
B (10) Ireland S. .	...	(73)	68	172	233	(260)	...	308	...
C (5) England S.E.	18	43	37	181	238	291	263	307	294
D (4) Midlands .	27	41	38	180	229	275	268	299	291
E (3) England E. .	18	40	33	180	236	277	268	295	289
F (7) England N.W.	24	50	36	175	235	264	253	293	292
G (9) Ireland N. .	16	47	57	172	233	293	264	298	295
I (2) England N.E.	28	58	42	187	238	277	(259)	(290)	282
J (1) Scotland E. .	52	50	47	(184)	(233)	256	(257)	288	(244)
Records used .	70	104	105	81	78	73	22	49	34
Mean of all . .	24·9	49·4	43·6	178·7	233·3	275·2	262·6	300·0	286·1
Month and Day .	J. 25	F. 18	F. 13	Je. 28	Ag. 21	O. 2	S. 20	O. 27	O. 13

Values in brackets indicate a single record only.

October, when in many parts the water level was still low, found all remarkably green and flowery, a condition everywhere abruptly ended about the 26th by exceptional frost. Leaves then first fell freely.

Tree Flowering, garden and wild, was universal. Rarely within memory, if ever, had hedges so whitened with sloe and may. The latter turned pink to an exceptional extent.

Much Second Flowering may be ascribed to the early heat and later coolness. From various parts came reports of the wild rose in September, sometimes several on a spray (Purley, Pocklington).

Tree Fruiting naturally followed the 1921 heat and 1922 spring cold. Even trees and bushes, such as holly, which had flowered exceptionally young, bore heavy crops. Of other wild kinds, hips, haws, and privet stand out. "Never such hips, haws, and holly," says D 29. A 20-year-old almond (G 6) bore its first crop. Passing northward, colour and flavour were poor, and at J 8 "wild fruits, as hazel, beech, oak, failed to ripen because of the sunless summer." Acorns were generally scarce ; beech-masts the reverse, though often failing to fill out. In spring 1923 Bucks beechwoods were carpeted with seedlings.

Second Fruiting was common, especially of strawberries (garden and wild) and raspberries.

Crops, when garnered, were better than feared. Welsh and Pennine areas, as well as Scotland, report much uncut in October. Second early and late crop potatoes did very well and were unexpectedly free of disease. Some ascribe this to the excellent seed from 1921.

General Bird Notes.—*Increasing* numbers are reported of owl, wren, jay, magpie, starling, thrush, missel thrush, blackbird, nuthatch, green woodpecker, long-tailed tit, gold-crest, goldfinch, chaffinch, greenfinch, bullfinch, yellow-hammer, and swift. The wax-wing was widely noted, as if driven across by the continental cold. *Decreasing* were the lark (in far west), corncrake, wryneck, redstart (Midlands), tree pipit, sedge warbler, whitethroat, whinchat, and swallow. Finches are conspicuous in the former list, warblers

TABLE VIII.—OBSERVATIONS OF TREES AND SHRUBS TAKEN AT ST. MICHAEL'S, TENBURY, WORCESTERSHIRE, 1922, BY FREDERICK LOWE.

Date given by day of year. For equivalent monthly dates see explanation on p. 251.

Common Name.	Latin Name.	First Flower.	First Leaf.	Full Leaf.	First Tint.	Full Tint.	Leafless.	Fruit Ripe.
1. Alder	*Alnus glutinosa*	57	129	142	270	297	314	274
2. Apple (Wild)	*Pyrus malus*	137	124	142	242	300	309	286
3. ,, (Cultivated)	*Pyrus malus sativus*	134	114	137	236	271	316	258
4. Ash	*Fraxinus excelsior*	106	133	142	252	281	301	277
5. ,, (Mountain)	*Pyrus aucuparia*	140	108	136	236	290	304	231
6. Acacia	*Robinia pseud-acacia*	159	134	144	253	297	309	268
7. Almond	*Amygdalus communis*	87	120	134	251	298	309	299
8. Berberis	*Berberis Darwinii*	118	128	140	...	...	...	195
9. Berberis	*Berberis aquifolium*	21	134	141	...	...	...	221
10. Barberry	*Berberis vulgaris*	141	106	128	240	300	312	243
11. Blackthorn	*Prunus spinosa*	117	127	138	244	300	314	270
12. Birch	*Betula alba*	128	118	130	223	281	308	240
13. Beech	*Fagus sylvatica*	133	125	130	240	281	304	241
14. Bullace	*Prunus insititia*	125	120	130	238	288	309	268
15. Box	*Buxus sempervirens*	46	62	124	...	...	...	...
16. Currant (Black)	*Ribes nigrum*	118	62	118	225	273	309	180
17. ,, (Red)	*Ribes rubrum*	110	99	128	222	259	291	178
18. Chestnut (Horse)	*Æsculus hippocastanum*	137	115	130	236	270	299	269
19. ,, (Spanish)	*Castanea vesca*	195	131	144	247	290	314	273
20. Cherry (Wild)	*Prunus avium*	114	118	131	244	288	303	200
21. ,, (Bird)	*Prunus padus*	142	127	133	246	288	308	203
22. ,, (Cultivated)	*Cerasus vulgaris*	124	120	137	241	288	304	174
23. Cypress (Common)	*Cupressus sempervirens*	93	132	141	...	...	...	267
24. Cedar	*Cedrus libani*	272	87	132	(Cas	ting	124)	305
25. Dogwood	*Cornus sanguinea*	157	127	137	203	274	301	268
26. Deutzia	*Deutzia crenata*	159	59	124	258	317	333	220
27. Elm (Common)	*Ulmus campestris*	59	138	149	269	311	327	135
28. ,, (Cornish)	*Ulmus stricta*	75	127	137	246	301	316	127
29. ,, (Cork)	*Ulmus suberosa*	61	138	145	241	291	310	136
30. ,, (Wych)	*Ulmus montana*	72	133	140	233	279	300	138
31. Elder	*Sambucus nigra*	148	22	124	232	291	304	244
32. Fir (Spruce)	*Abies excelsa*	117	130	138	(Cas	ting	229)	259
33. ,, (Scots)	*Pinus sylvestris*	132	139	150	(Cas	ting	229)	274
34. Gooseberry	*Ribes grossularia*	96	63	118	219	268	301	188
35. Gorse	*Ulex europæus*	1	113	138	...	...	...	219
36. ,, (Dwarf)	*Ulex nanus*	220	154	175	...	...	...	314
37. Hazel	*Corylus avellana*	28	114	134	236	273	304	242
38. Hawthorn	*Cratægus oxyacantha*	137	108	128	233	288	309	241
39. Holly	*Ilex aquifolium*	143	140	154	(Cas	ting	144)	271
40. Honeysuckle	*Lonicera caprifolium*	141	8	108	219	267	309	203
41. ,, (Wild)	*Lonicera periclymenum*	157	1	117	232	288	311	233
42. Ivy	*Hedera helix*	254	127	140	(Cas	ting	89)	56
43. Japonica	*Pyrus japonica*	34	21	82	259	301	333	263
44. Jasmine (Yellow)	*Jasminum nudiflorum*	277	83	133	213	287	310	...
45. ,, (White)	*Jasminum officinale*	195	141	154	277	309	332	...
46. Kerria	*Kerria japonica*	85	73	134	227	298	320	...
47. Laburnum	*Cytisus laburnum*	141	120	140	209	308	319	245
48. Laurustinus	*Viburnum tinus*	1	51	115	...	...	...	244
49. Laurel (Portugal)	*Cerasus lusitanica*	167	123	148	232	(Cg.	120)	277
50. ,, (Spurge)	*Daphne laureola*	1	56	124	(Cas	ting	120)	182
51. ,, (Variegated)	*Aucuba cerasus*	124	79	144	(Cas	ting	118)	...

Where used, Cg. indicates "Casting."

TABLE VIII.—OBSERVATIONS OF TREES AND SHRUBS TAKEN AT ST. MICHAEL'S, TENBURY, WORCESTERSHIRE, 1922—*continued.*

Common Name.	Latin Name.	First Flower.	First Leaf.	Full Leaf.	First Tint.	Full Tint.	Leafless.	Fruit Ripe.
52. Laurel (Common)	*Cerasus laurocerasus*	115	135	148	(Cas	ting	60)	271
53. Larch	*Pinus larix*	92	104	127	244	302	317	244
54. Lilac	*Syringa vulgaris*	135	114	131	241	291	304	277
55. Lime	*Tilia europæa*	199	128	141	232	268	301	266
56. Lavender	*Lavendula vera*	224	60	112	(Cas	ting	245)	266
57. Maple (Field)	*Acer campestre*	137	134	142	244	277	300	271
58. ,, (Norway)	*Acer platanoides*	116	128	137	236	273	289	266
59. Medlar	*Mespilus germanica*	144	99	125	259	302	319	297
60. Mezereon	*Daphne mezereum*	1	57	118	233	300	309	191
61. Mistletoe	*Viscum album*	54	136	156	268	(Cg.	87)	335
62. Oak	*Quercus robur*	135	130	143	259	308	328	281
63. ,,	*Quercus sessiliflora*	135	130	142	253	291	312	279
64. Poplar (White)	*Populus alba*	73	129	136	243	281	302	128
65. ,, (Grey)	*Populus canescens*	103	140	147	249	301	313	133
66. ,, (Black)	*Populus nigra*	77	130	137	233	272	299	127
67. ,, (Lombardy)	*Populus fastigiata*	102	125	138	233	288	302	119
68. ,, (Aspen)	*Populus tremula*	69	138	141	248	278	300	118
69. Privet	*Ligustrum vulgare*	164	104	127	231	(Cg.	249)	263
70. Pear (Common)	*Pyrus communis*	124	126	137	236	268	300	258
71. Plum (Common)	*Prunus domestica*	111	116	133	236	277	300	261
72. ,, (Pershore)	*Prunus Pershorum*	124	115	136	240	281	299	237
73. Quince	*Cydonia vulgaris*	141	97	129	266	307	319	296
74. Ribes	*Ribes floridum*	97	73	118	232	288	310	...
75. Rosemary	*Rosmarinus officinalis*	66	58	119	(Cas	ting	245)	225
76. Raspberry	*Rubus idæus*	145	68	124	213	288	316	188
77. Rose (Guelder)	*Viburnum opulus*	148	127	143	240	276	294	223
78. ,, (Field)	*Rosa arvensis*	167	98	128	213	266	304	265
79. ,, (Dog)	*Rosa canina*	152	94	124	209	288	304	254
80. Service (Wild)	*Pyrus torminalis*	149	129	143	246	291	308	261
81. Snowberry	*Symphoricarpus racemosus*	157	99	125	242	301	310	245
82. Syringa	*Philadelphus coronarius*	149	87	125	225	267	281	232
83. Spindle	*Euonymus europæus*	150	114	134	242	289	310	274
84. Sycamore	*Acer pseudo-platanus*	118	113	130	242	277	300	260
85. Traveller's Joy	*Clematis vitalba*	173	115	146	263	301	316	...
86. Willow (Goat)	*Salix caprea*	102	128	138	232	281	300	150
87. ,, (Common)	*Salix fragilis and viminalis*	128	118	130	222	282	308	164
88. ,, (White)	*Salix alba*	130	124	132	236	301	319	169
89. Walnut	*Juglans regia*	144	128	145	236	293	304	269
90. Yew	*Taxus baccata*	50	128	145	(Cas	ting	157)	226

Where used, Cg. indicates "Casting."

Trees generally in full leaf, 143. Autumn tints generally beginning, 270.
First heavy fall of leaf, 288. Tints full generally, 299.
Trees generally leafless, 328.

Trees much advanced during mild weather in January, but completely checked by continuous cold during February, March, and April.

Remarkably heavy blossom on all trees.

Fruit of all kinds abundant.

in the latter, a fact also insisted on in the Yorkshire Naturalists' Association Report. Two or three cases of very late breeding by the house martin are reported, broods only leaving the nest in late October. Abundant food made even swifts stay on.

FROGSPAWN is only thrice recorded, giving the late mean of 63 (March 4).

INSECTS.—Meadow browns abounded ("Countless," C 4), also brimstone, but moths were very scarce and many butterflies, *e.g.* tortoiseshells, peacock, red admiral, and the whites in many parts. An irruption of clouded yellow signalized the year. Wasps were very scarce till late ; then not universal.

GARDEN AND FIELD PESTS.—There was a marked absence of aphis blight all summer in most parts. At Purley it was noted in December 1921 on roses and cabbages. Houseflies also were rarely troublesome. During and after the heat spell, frit-fly and wire-worm damaged oats, and turnip-fly was hurtful. Oaks were again stripped in several parts, but less than in the last few years. On the whole, vegetation was unusually free, earwigs and woodlice alone being specially troublesome. The latter multiplied abnormally, no doubt, in 1921.

CORRIGENDA, 1921 REPORT.

P. 298. Reverse the station numbers in B of Mountmellick and Ferns.

P. 306. 17a Redhill, nr. Wrington.

DISCUSSION.

The PRESIDENT (Dr. C. Chree, F.R.S.) said a report of this kind meant a great deal of work. It represented results that we hoped the next generation would be better able to appreciate than ourselves. We hoped that these results systematically recorded might serve to substantiate gradual changes of climate we might otherwise fail to detect. One of the possibilities in a country like this was that conditions might be changed by the increased industrialism of mankind.

Mr. R. H. HOOKER, in congratulating the Reporters, reminded Fellows that the chart of isophenes, which was perhaps the most interesting summary, was entirely due to Mr. Clark. He was pleased to see that the curves now were not so erratic as they were in the first tentative charts in the earlier reports, which showed so many wobbles. These latter might be attributed no doubt in part to the exposure of the locality in which the observations were taken. What was still wanted, however, was to get isophenes representing not merely the actual spot, but the district. The plants were affected so much by altitude that the isophenes would be greatly altered if an observer were one or two hundred feet higher or lower. He thought there ought to be a possibility of making some correction for altitude. The ordnance maps would show the mean level of the district, and knowing the height of the position they could correct the isophenes accordingly instead of merely drawing a circle round an abnormally high station. The abundance of fruit last year was certainly striking ; what was even more striking was the abundance of fruit still remaining on the trees now. The hips and haws and the holly-berries remained throughout the winter, so that this year we had hawthorns in flower and fruit at the same time. Another curious effect he had observed was shown by the beech seedlings this year. He had noticed beech woods where these seedlings were about an inch high, before the cotyledon leaves had burst: a multitude of these still had the shell of the nut at the top of the young stem so that they appeared like an army of tiny fairies each with a brown helmet on.

Mr. I. D. MARGARY joined Mr. Clark in thanking the Meeting for the kind reception of their work. The loss of Mr. Adames made a great difference to them, as well as to the Society in the phenological work. The other more encouraging feature of the year was the remarkable increase in the number of new observers. The appeal this year was so extraordinarily successful that they were deluged with applications and ought to be well over the three hundred standard this next year. This would make considerably more work for them, and he and Mr. Clark would be glad if some one would be willing to join in preparing the report.

Mr. L. C. W. **Bonacina** thought the attention of the Society should be directed to Fig. 2, map of average isophenes, which are in harmony with Hopkins's bio-climatic law brought before the Society two years ago. That law was the one really valuable generalization that these observations had evolved so far. According to it the spring comes one day later every 25 miles to the north and every hundred feet upwards. There is no definite relation to longitude which in the British region is a measure of differences in the continentality of the climate. He wanted to ask Mr. Clark if he saw his way to relating the autumn functions of vegetation—the fruiting and defoliation—as distinct from the spring functions, to that law, because the theory was very interesting. Suppose in the north of Scotland the leaves of a given species come out two or three weeks later than in the south of England, will they fall two or three weeks earlier in the north of Scotland because of the colder climate and earlier frosts? Or will the leaves hold on longer in order to give the fruit or seed, which is later in the north on account of the later flowering and cooler summer, a chance to mature? In other words, what sort of compromise is there in the north between the external factor of earlier winter which makes for earlier defoliation and the internal plant factor which tends to make defoliation await fructification? The answer would solve a fundamental problem in phenology.

Rev. A. E. **Swinton** said there was one question he would like to ask and that was whether there was any information about the lateness of the disappearance of migrants. He wondered whether this had any connection with the observation that the defoliation was exceptionally late last year and whether that would bear on what the last speaker had pointed out. The influence of the October warmth was the greatest factor in the unusual flowering last year. We do not see any excess of flowering this year, and he wished to know whether it was the influence of October or not.

Mr. J. E. **Clark** in reply said that it was of great personal interest to him to present the Report each year. He had had to give up other things in order to devote more time to it. He had been interested in some of the criticisms, and especially Mr. Hooker's remarks with regard to altitude, but they simply had not been able to deal with that because there was so much else to be taken into account. It was one of those things Hopkins's bio-climatic law dealt with, as had been stated. There again they missed Mr. Adames, who had taken as his work the entering into the correlation which that law enabled them to follow up, and they were therefore at a loss this year. As would be seen by the chart, height accounted for many of the irregularities. As to the functions affecting autumn ripening of crops they had hardly been able to touch that. It was evident that the matter was of very great moment. Hopkins's bioclimatic law would certainly prove of immense value in this direction. He would like to refer to what his colleague had said, that they would appreciate every help in carrying on the work. With reference to the late spring profusion of berries this year such a case is practically unknown before. Even last Sunday on Riddlesdown some hollies were scarlet from last year's berries. The beech seedlings were of great interest. The lateness of the disappearance of the migrants was just referred to in the Report, and the extra table showed something of it. That should be compared with the late nesting, as was instanced by reports of late broods of martins whose young were fledged in October. As to the influence of last October, we must remember there were many influences at work, and he ventured to suggest it was largely counteracted by the previous two conditions of the dull summer and the heavy fruiting that had taken place last autumn.

METEOROLOGICAL NOTES FROM THE MOUNT EVEREST EXPEDITION OF 1922.

By T. G. LONGSTAFF, M.D., F.R.Met.Soc.

[Received June 2—Read June 20, 1923.]

The scope for meteorological and physical investigations on very high mountains is almost unlimited, but the attendant restrictions and difficulties are such as can hardly be realized by those who have not personal experience of the conditions of life at high altitudes. On this expedition every other consideration had to give way to the climbing of the mountain, and the time and energies of every member of the team were sufficiently occupied thereby. It appears, however, that an attempt should be made to put on record the few meteorological observations we were able to bring back.

Major H. T. Morshead, R.E., D.S.O., had charge of our instruments. These had all been carefully selected, corrected, and compared. The annexed tables of temperature (F.) are from observations taken under his direction by different members of the party. Night minima were taken with spirit thermometers exposed to the sky about one foot above the ground on wooden boxes. The day temperatures were taken with sling thermometers. Major Morshead took all the observations at the high camps.

TABLE I.—Air Temperature by Sling Thermometer. Base Camp at 16,500 Feet.

May.	8 h.	12 h.	16 h.	May.	8 h.	12 h.	16 h.
	°F.	°F.	°F.		°F.	°F.	°F.
16		45		23	32		42
17	30			24			
18	36	42·5		25	42		
19	42	47		26	36·5		48
20	39·5	48	41·5	27	43	50	45·5
21	34	43	37	28		49	
22							
				Mean	35·3	46·4	43·0

Note.—The readings printed out of alignment were taken somewhat later than the hour stated at the head of the column.

Readings at High Camps. May 19, 17 h. Camp IV., 23,000 feet . . +9° F.
,, ,, ,, 20, 17 h. ,, V., 25,000 ,, . . 0
,, ,, ,, 21, 12 h. ,, V., 25,000 ,, . . +5

It will be noted that the Base Camp (16,500 feet) was particularly cold and windy. Camp I. (17,500 feet) was warm and sheltered; its relatively and often actually higher night minima emphasize this fact. Camp II. (19,250 feet) was again very cold and sunless, though not continuously wind-swept like the Base Camp. Camp III. (21,000 feet) was relatively warm and sunny; its night minima were relatively and occasionally actually higher than at Camp II.

Camp I. is 1000 feet higher than the Base Camp, but the average of its (13) night minima (when observations are available at both places) is 0°·6 F. higher. Camp II. is 1750 feet higher than Camp I., and the average of its (7) night minima is 16° F. lower. Camp III. is again

1750 feet higher than Camp II., but the average of its (7) night minima is only 1°·4 F. lower.

It is essential to remember that these notes deal only with conditions during April, May, and half June, on the northern side of the main Himalayan axis of elevation. Considerable areas of Tibet lie on the southern side, but there meteorological conditions are totally different, the change from one to the other being extraordinarily abrupt. The classical account of the climate of the Tibetan highlands is contained in the late Colonel Henry Strachey's "Memoir on the Physical Geography of Western Tibet," published by Wm. Clowes in 1854, and read in part before the Geographical Society on November 22, 1853.[1]

TABLE II.

MINIMUM TEMPERATURES RECORDED BY RADIATION THERMOMETERS EXPOSED TO THE SKY ON BOXES ABOUT ONE FOOT FROM THE GROUND.

	Camps.					
	Base	I.	II.	III.	IV.	V.
Height in thousand feet.	16·5	17·5	19·2	21·0	23·0	25·0
1922	°F.	°F.	°F.	°F.	°F.	°F.
May 2	13					
3	11					
4	11					
5	16					
6	14	21				
7	17		+13			
8	13		− 2			
9	9					
10	13	15	− 5			
11	7					
12	7					
13	6	7				
14	21	12		0		
15	...	17	+ 1			
16	23	19	+ 9	+ 4		
17	0	6	− 8	− 7		
18	8	8		− 6		
19	10	9	−10	− 7		
20	7		+ 2		−11	
21	15	22	− 4	− 2		− 7
May 22	9	7		− 9		
23	5	12	+ 2	− 9		
24	13		− 3	− 3		
25	5		− 7	− 7		
26	13	10		0		
27	10			−12		
28	11			− 6		
29	12					
30	13·5	11				
31	...					
June 1	7					
2	7					
3	17	Monsoon approaching.				
4	24					
5	22					
6	15					
7	16					
8	20	Monsoon approaching.				
9	30	Monsoon snowfall.				
10	30					
Mean	13·2	12·6	−1·0	−4·9	...	...

Readings on the outward march, April 12 to May 1; Height 13,600 to 16,000 feet.

Highest Reading	24° F.	at 13,600 feet.
Lowest "	8° F.	13,800 "
Mean "	15° F.	..

We observed signs of desiccation about Shekar Dzong and in the upper Arun (Pung Chu) Valley. Ruined castles, farms, and villages, together with derelict irrigation channels, cultivation terraces, and field walls, were numerous. This part of Tibet must have supported double the present population in historic times; but history, and even tradition, are notoriously silent in Tibet on such matters.

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[1] *Serie Prima, Vol. III, Meteorologia*, of the "Relazioni Scientifiche della Spedizione Italiana di Filippi nell' Himalaia," now in course of publication by Zanichelli of Bologna, gives us the first complete account of Meteorology at high altitudes.

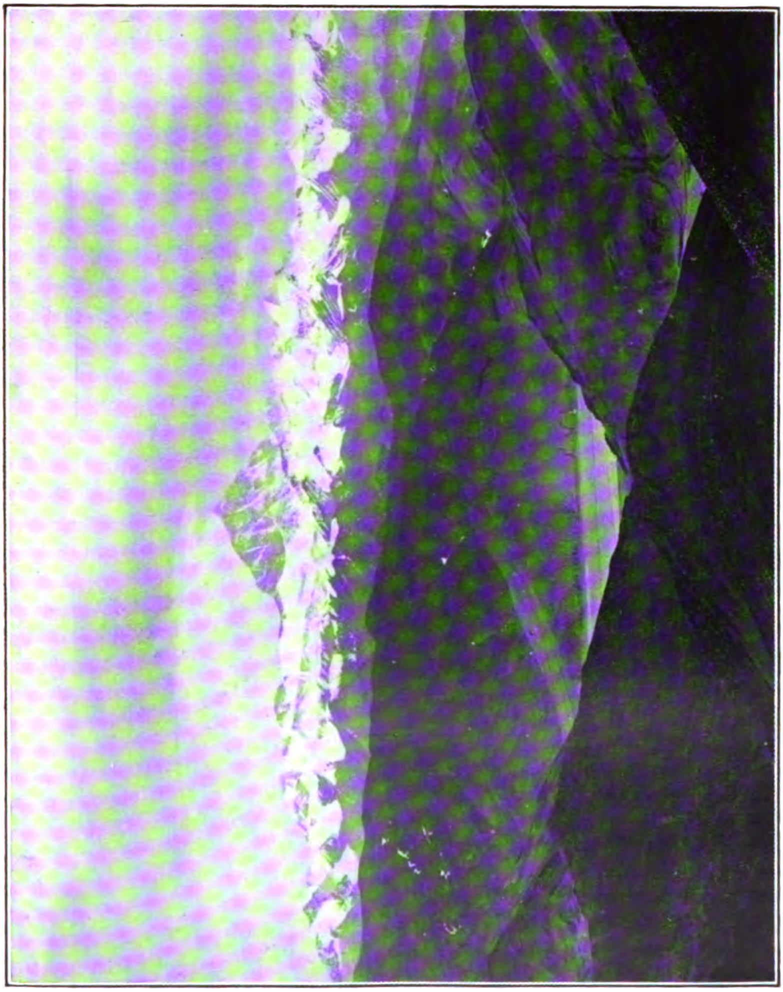

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FIG. 1.—Mount Everest from the Rongbuk Valley.

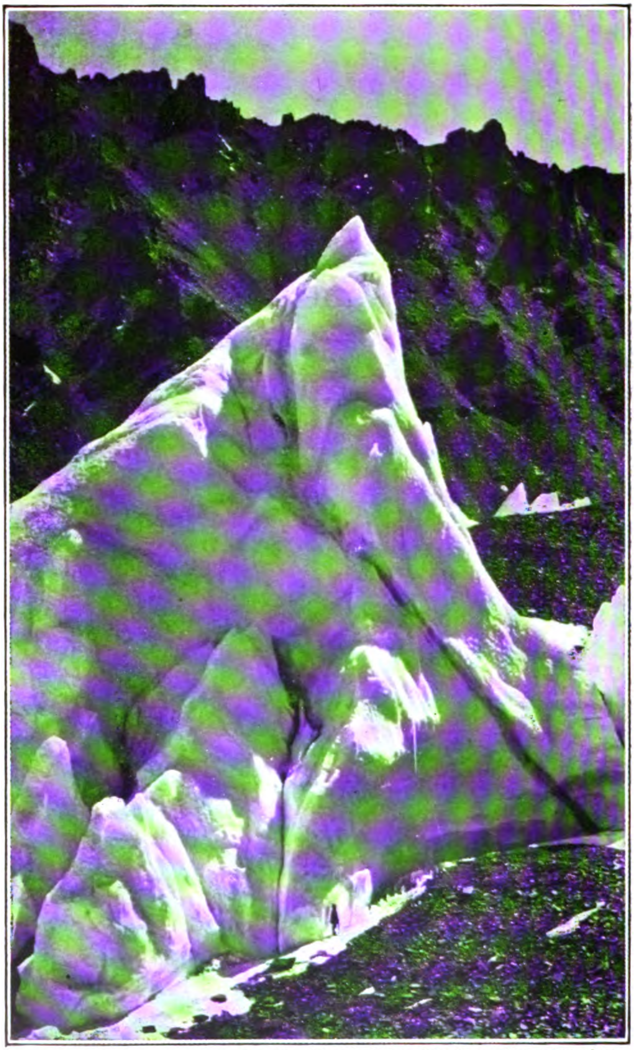

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FIG. 2.—Serac on the East Rongbuk Glacier.

On the north side of Mount Everest the snow level may be put at 20,000 feet, and glaciers descend to 16,500 feet. The old moraines indicate a comparatively recent diminution of the ice. The glaciers are small, considering the height and mass of Mount Everest, in comparison with the glaciers of the Karakoram; but even so their effluent streams are feeble; these can be waded, at least before the monsoon. The intense degree of evaporation which obtains reduces their surface to a series of fantastic pinnacles and towers. I observed the same phenomenon on the glaciers of Gurla Mandhata in 1905, and to a somewhat less degree on the Siachen and Remo glaciers of the N.E. Karakoram in 1909, though in the latter range extreme honeycombing of the surface is more characteristic. Owing, I suppose, to the extreme dryness combined with the increased diathermancy of the air at these high altitudes, evaporation is incredibly rapid. It is scarcely an exaggeration to say that above 25,000 feet snow does not melt, but literally evaporates into the thin air. Thus ice is rarely met with at great altitudes, and the risk of avalanches is increased, for fresh snow cannot freeze firmly to the layer beneath. We got our first good view of Everest from the Pang La on April 28. The whole north face of the mountain was so free from snow and ice that it was long before I could be persuaded that this was indeed Everest. Such conditions obtain even at lower altitudes, and snow lies but a very short time on the Tibetan Uplands. We camped in a blizzard at 15,000 feet on April 8, but next morning the snow was soon gone, and we found the ridges of Pawhunri dry at 17,000 feet. We awoke at the Base Camp (16,500 feet) on June 4, to find 4 inches of snow on the ground; by 10 o'clock the ground was dusty. Probably the constant high winds greatly assist this phase. Have we weighed the potential possibilities of increased evaporation, as opposed to positive decrease in rainfall, in the production of progressive aridity?

No *bas-névé* was met with, and this may also be attributed to the rapidity of evaporation, for such dead masses of consolidated snow, lying in sunless ravines or protected by a covering of mountain debris, are not uncommon in the damper portions of Tibet lying to the north and west. Schlagintweit has noted them in the Kuen Luen, and I have seen them both in Tibet and in the true Himalaya.

The weather on the Tibetan Uplands is generally clear and dry. The approach of the monsoon brings high cumulus, but the clouds are not very dense. We experienced only one heavy fall of rain, with thunder, on June 10, at 14,000 feet. A low-level wind blows from the West or SW, laden with dust, and with insufferable regularity from 9 a.m. to sunset. It is frequently so strong that to pitch tents is difficult. Occasionally a high-level North wind gave us a quiet day. Usually there is a high-level Westerly gale above 23,000 feet, shown by blown snow. The monsoon blows up from the South, usually mastering the West wind early in June. It is heralded by a peculiar haze over the mountains.

Figs. 1 and 2 are reproduced by kind permission of the Mount Everest Committee. They are reprinted from the October 1922 number of the *Geographical Journal* (vol. 60, No. 4), to which the reader is referred for a series of very excellent photographs taken during the expedition.

DISCUSSION.

The PRESIDENT (Dr. C. CHREE) said that they had been shown pictures of striking meteorological interest. The apparently increasing desiccation was a serious feature.

Dr. G. C. SIMPSON said that he was interested in what Dr. Longstaff had said, and could not help comparing the conditions on Mount Everest with his own experience in the Antarctic. The first thing which interested him was Dr. Longstaff's description of the absence of water. This surprised him, because the temperatures were not very low. At the base station on Mount Everest the temperatures rose well above the freezing-point—48° and 47° F.—in the day time. In the Antarctic, with temperatures well below freezing-point, there was in the summer much water at places where black rock and snow were in juxtaposition. It is probable that the absence of water on Mount Everest could be accounted for by the great evaporation, the water being evaporated as soon as formed. In the Antarctic the snow surface was never wet away from rocks for a similar reason. In spite of the great evaporation on Mount Everest the presence of glaciers showed that the evaporation did not exceed the precipitation. There was one meteorological fact which interested him, but to which the lecturer had not referred, and that was the whale-back clouds over the mountain shown in the photographs. They had such clouds well developed over Mount Erebus in the Antarctic after blizzards. He hoped that the results would be worked up and that some one connected with the Society would co-operate with Dr. Longstaff in getting out of the observations all facts of meteorological importance.

Dr. G. T. WALKER drew attention to the large part played by radiation from the ground in controlling temperature in the tropics. On clear nights in the cold weather at the hill stations of northern India the air which is chilled by proximity to the ground escapes downhill, and is replaced by air at about 38° F., of which there is an inexhaustible supply ; out in the plains the air near to the ground cannot escape and its temperature falls to about 35° F. At Simla it is found that in a site where the air is imprisoned by surrounding slopes its minimum temperature is 18° lower than that on the ridge above ; and a skating rink can be flooded at 10.30 in the morning in order to form excellent ice six hours later. These low temperatures are necessary for explaining the very strong winds that are experienced in Seistan and the high regions of Central Asia.

Mr. L. C. W. BONACINA wished to refer to the point as to whether the temperature near the level to which the travellers attained on Mount Everest is not about as cold as it would be if the Himalayas were at the north or south pole. From what is known about the stratosphere in the free air, the summit of Mount Everest must be in a level of low horizontal temperature gradient and near the point where the vertical temperature gradient ceases. With regard to clouds, he thought the observations were a positive illustration of the extent to which water cloud exists far below the freezing-point. When he read the account of the climbing party,[1] it appeared that they passed through dense mists without recording a drift of ice crystals, as they should have done in an ice cloud. The frequency with which ordinary-water cloud and mountain-mist were seen and encountered even at the highest Himalayan levels was noteworthy.

Dr. T. G. LONGSTAFF, in reply, said he did not think they would get any good observations from Mount Everest for a good many years to come. Until the top of Everest has been reached you would not get people to do real scientific investigations of mountains any more than until the poles were reached did you get people to do the real scientific exploration of the polar regions. If the temperatures were of any value the Everest Committee would be much gratified by their publication.

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[1] *Geog. J.*, **60**, 1922, p. 385.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

June 20, 1923.

At the *Ordinary Meeting* the following candidates were balloted for and elected Fellows of the Society :—

HANS RAJ ANAND, M.R. San. Inst., P.O. Raya, Beas District, Amritsar, Punjab.
WILLIAM CHARLES DILLON HILLS, M.R.C.S., D.P.H., M.O.H., Queensborough, Sheerness, Kent.
GEORGE THOMAS LEWIS, Weston, Newtownbarry, Co. Wexford ; and
JAMES LOUIS NORTH, Curator, Royal Botanic Society, Regent's Park, N.W.1.

The PRESIDENT (Dr. C. Chree) referred to the great loss sustained by the Society through the death of one of the authors of a paper mentioned in the Minutes of the last Meeting. Mr. Salter had died since the paper was read. Mr. Salter had done a vast amount of useful work in connection with the British Rainfall Organization and at the Meteorological Office, where he had been a colleague of his own. He felt he could not pass to the business of the Meeting without a reference to the sad event.

After the reading of the Phenological Report and of a paper by Dr. T. G. Longstaff, Mr. ROWLAND ARNISON explained to the meeting the working of a new form of open-scale barograph which had recently been brought out by Messrs. Short & Mason.

CORRESPONDENCE AND NOTES

Note on indoor temperatures in Cairo during the summer of 1922.[1]

During the summer of 1922 the writer kept a daily record of maximum and minimum temperatures indoors in Cairo. The room was on the third floor and faced east towards an open space, the nearest buildings opposite being about eighty yards distant, so that the outer wall of the room was freely exposed to the sun and wind. In accordance with the usual procedure in Egypt, in the daytime the windows were shuttered, while at night they were open. The readings are shown on the accompanying diagram, which for purposes of comparison shows also the extreme day and night temperatures in the thermometer screen placed in an open space near the centre of Cairo, viz. Ezbekia Gardens.

It may be mentioned that throughout the summer the weather was very trying to most people. It was hotter and slightly damper than usual, the mean temperature in Cairo from July to October inclusive being 81° F., *i.e.* 1°·5 F. above normal, while the mean relative humidity during this period was 68 per cent, *i.e.* 2 per cent above normal. The mean vapour pressure was 20 millibars.

From the middle of June until the end of August the temperature in the room did not at any time fall below 80° F., while the average lowest temperature during the nights was 83° F. On the warmest night the temperature in the room was 86° F. In Ezbekia Gardens, at a height of five feet from the ground, the average night temperature during this period was 71° F., while on the

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[[1] Reference should be made to a note by Mr. Walter Clemence entitled "Summer temperature records in the Middle East," which appeared in the *Quarterly Journal*, July 1922, pp. 278-280. In this note Mr. Clemence shows graphically the difference in temperature between outdoor conditions and those prevailing in a well-ventilated room in the city of Baghdad from June to September 1921.—*Editing Committee.*]

warmest night the temperature was 77° F. Thus a person sleeping in an east room on the third floor had to put up with a temperature about 12° F. higher than that which would have been experienced by any one sleeping in the open near ground level, and in addition of course he would not have the full benefit of such breeze as there was—a factor of considerable importance in assisting evaporation from the skin and augmenting bodily comfort.

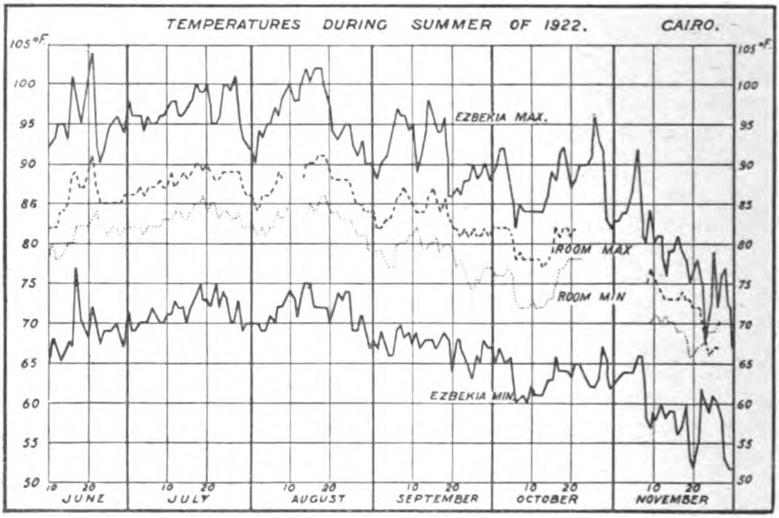

FIG. 1.—Diagram showing daily readings of maximum and minimum temperatures indoors and in the open in Cairo (Ezbekia).

The warmest day had a shade temperature in the open of 104° F., while inside the room it was 91° F. The average daily maximum in Ezbekia Gardens from the middle of June until the end of August was 96° F. ; in the room it was 9° F. cooler. The difference between night and day temperatures inside the room averaged only 4° F., viz. from 83° F. to 87° F., while in the open the change was 25° F., viz. from 71° F. to 96° F. L. J. SUTTON, M.A.

An Alpine Mirage.

The following letter appeared in the *Times* of May 11, 1923 :—

"An occurrence apparently of a rather extraordinary mirage in the Alps may be of interest to your readers, especially to those who may be mountaineers. Mr. F. S. Smythe and I were climbing the Finsteraarhorn in the Bernese Oberland on May 2, a day of perfect weather and extremely good visibility. When on the rock ridge within 300 or 400 feet of the summit, *i.e.* at an altitude of about 13,800 feet, we paused to admire the very fine panorama of mountains all round us. We could clearly identify the Black Forest some 150 miles to the north, and we saw snow-capped peaks in Italy certainly 100 miles or more to the south. All the giants of the Alps, Mont Blanc, Weisshorn, Matterhorn, Monte Rosa, etc., although some were thirty and forty miles away, stood out as if across the next valley. So clear was the air that the visible horizon to the north appeared to be certainly twice as far off as the Black Forest, although no definite features could be picked up beyond the Black Forest. Suddenly at 11.55 a.m. the image of a ship appeared in the sky just to the east of the Eiger peak, floating in a blue shimmer just beyond the visible horizon. This lasted for a minute or so, and then vanished.

Very soon after a line of five ships appeared farther east, funnels and masts clearly distinguishable. This image lasted for some fifteen minutes, and varied in its clearness from time to time. The ships appeared of course greatly exaggerated in size, and were right way up, not inverted. The direction of the five ships was in a line from Finsteraarhorn through Grindelwald. On reference to an atlas, this brings their position on the nearest sea to approximately the eastern exit of the English Channel into the North Sea, a distance of some 400 miles.

"This would appear a most extraordinary distance for a mirage, if such it was. Both Mr. Smythe and myself saw the ships so clearly that we could not have mistaken any cloud effect for ships. It would be interesting to know of any experience of mirage over desert areas comparable to this, or of any other mirages seen from the Alps. I have no personal knowledge of any other such experiences. P. NEAME, Lieut.-Col., R.E."

[The following notes on the meteorological conditions accompanying the mirage and exceptional visibility on May 2, 1923, have been received.—*Editing Committee.*]

At 13 h. on May 2 the British Isles and Southern Europe were for the most part under the influence of two anticyclones centred off the west coast of Scotland and over Southern Europe respectively.

The only definite wind current at the surface was a moderate to fresh E wind over the Channel, due to a depression west of the Bay of Biscay. The sky was practically cloudless at this time over France and Switzerland, and the surface temperature was abnormally high, being between 70° and 80° in the north of France and even higher in the south. Although surface winds were variable and light on the continent, pilot balloon ascents made at Rochefort and Amiens showed that there was a definite South-Westerly wind higher up during the morning, reaching 20 to 30 m.p.h.; moreover on Säntis (8000 feet) similar winds were observed at this time. The upper winds observed in France on the preceding day also showed a drift of air from SW, with a similar wind at Säntis (see Table I.).

The anticyclone over Southern Europe, unlike the anticyclone off the Hebrides, had persisted since April 30, and with a depression out on the Atlantic to the west, conditions for the two previous days had been very favourable for a general drift of surface air up from the south. That such a drift actually took place is evident from the general rise of temperature that occurred between April 30 and May 2 over France. At Säntis also the temperature rose during this period, and reached 43° F. at 13 h. on the 2nd. The exceptionally good visibility occurred therefore in "equatorial" air.

It is unfortunate that no observations of temperature in the upper air are available for Switzerland or France on that day, but after a careful examination of the synoptic charts and upper winds observed at about this time, I came to the conclusion that the observations made at the Helder at 9 h. on May 2 and those made at Friedrichshafen (Lake Constance) at 7 h. on May 1 (see Table II.), both represent air that had moved up a long distance from the south-west, and perhaps give an approximation to the conditions that prevailed over Switzerland up to about 10,000 feet at noon on the 2nd. It will be noticed that in both cases lapse of temperature with height is unusually small, and at the Helder practically ceases at 5000 feet. There is no evidence of an actual inversion of temperature, and the great rise of surface temperature that took place between 7 h. and 13 h. would not have favoured the production of such an inversion.

On April 28 and 29 the southern anticyclone was south-west of Spain and was only beginning to extend towards Southern Europe. It seems possible therefore that the South-Westerly winds observed over France were part of the

TABLE I.—OBSERVATIONS OF UPPER WINDS MADE BY PILOT BALLOONS ON MAY 1 AND 2, 1923.

May 1.							May 2.				
	Clermont Ferrand, 5 h.		Rochefort, 13 h.		Argentan, 17 h.			Amiens, 9 h.		Rochefort, 12 h.	
Height above M.S.L. (feet).	Direction (degrees from North).	Velocity (m.p.h.).	Direction (degrees from North).	Velocity (m.p.h.).	Direction (degrees from North).	Velocity (m.p.h.).	Height above M.S.L. (feet).	Direction (degrees from North).	Velocity (m.p.h.).	Direction (degrees from North).	Velocity (m.p.h.).
	°		°		°		660	180°	9	225°	7
1,640	292	5	203	16	225	14	1,640	225	13	190	11
3,280	270	6	190	16	225	23	3,280	293	18	225	11
4,920	270	7	203	19	248	23	4,920	260	18	225	18
6,530	270	13	203	20	248	29	6,530	248	23	225	18
9,850	315	19	...	...	248	29	9,850	248	34	225	9
13,100	338	16	...	...	...	...	13,100	...	...	225	16

TABLE II.—TEMPERATURES AND HUMIDITIES IN THE UPPER AIR.

1. Friedrichshafen, 7 h. May 1.			2. Helder, 9 h. May 2.		
Height.	Temperature.	Humidity.	Height.	Temperature.	Humidity.
feet.	°F.	%	feet.	°F.	%
			660	50	85
			1,640	48	75
3,280	47	76	3,280	45	85
4,920	44	70	4,920	37	75
6,560	45	32	6,560	37	75
8,200	40	24	8,200	36	45
9,840	34	21	9,840	32	45
12,470	24	20	13,120	32	...

circulation round this anticyclone at an earlier date and were drawn from the nearly permanent North-Easterly winds of the Sahara. These winds are often associated, according to Kendrew,[1] with very good visibility and traverse one of the hottest regions in the world. The combination of high temperature and exceptional visibility is readily explained if the air is assumed to have been at one time over the desert and to have been drawn off by steady winds of moderate strength without disturbance of the desert dust. E. V. NEWNHAM.

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[1] *The Climates of the Continents*, p. 25.

The illusion of distant ships would seem to be explicable by the presence of an inversion of temperature. If the boundary between the upper warm air and the lower cooler air was not quite level, one part of the boundary might be so placed as to totally reflect light from distant ground, whilst another part would let through light from above. The illusion of the ship's masts is comparable with that of reeds growing by the edge of water in the "inferior" mirage of the desert. A similar drawing out of a small object can often be observed through a window-pane of poor glass. As will be seen from the notes prepared by Mr. E. V. Newnham, the circumstances under which the mirage was observed were of great interest from the meteorological point of view. It will be noticed that there is no positive evidence for the inversion of temperature observed at 7 h. on May 1 persisting until noon the next day; in fact, in the circumstances of May 1 a ground temperature of 300*a* (81° F.) would have produced convective currents strong enough to wipe out irregularities of temperature at levels below 2 km., where the air was already at 280*a* (45° F.), the limiting lapse rate being 10° C. per kilometre. A moderate rise in the upper air temperature between the 1st and 2nd would, however, have allowed of the persistence of the inversion throughout the day on which the mirage was seen.

F. J. W. WHIPPLE.

OBITUARY.

Mrs. C. H. BUTTERWORTH.

On August 4th, at her residence at Ben Rhydding Road, Ilkley, occurred the death of Mrs. C. H. Butterworth, who had been a Fellow of the Society for over twenty years.

Mrs. Butterworth was a niece of the late Dr. James Nicol, who commenced a series of regular meteorological observations at Llandudno more than 60 years ago. The instruments with which the Llandudno observations were made were for many years on property held by Mrs. Butterworth.

Mrs. Butterworth (née Charlesworth) was elected a Fellow of this Society on May 15, 1901.

The Council has also to record with regret the death of Captain JOHN MORRIS WHITTING of Mandalay, Upper Burma, which occurred on April 4. Captain Whitting was elected a Fellow on November 17, 1915.

REVIEWS.

Lufthülle und Klima. Von ALBERT DEFANT und ERICH OBST. *Enzyklopädie der Erdkunde*, Band 7. Leipzig und Wien (Franz Deuticke), 1923. 8°. Pp. viii + 186. Illustrated.

This work forms part 7 of a new and very detailed geographical series, which is intended to contain twenty-nine volumes and which should be of great value to students. The present part includes two sections: "Atmospheric processes" by A. Defant, and "Climate and its geographical distribution" by E. Obst.

The section on "Atmospheric processes" is in effect a text-book of physical meteorology. The author has endeavoured to give a concise account of the present position of those branches of the subject in which important recent developments have taken place. Thus the various sections are of very unequal length; for instance, fifty-one pages are devoted to an account of heat radiation and air temperature. The section on atmospheric pressure is sufficiently up-to-date to contain a good account of the polar-front theory. Another important section, which although it occupies only twenty-two pages, summarizes much recent work, is that on water-vapour in the atmosphere.

The geographical distribution of the various meteorological elements is treated very briefly, and there are no maps. Altogether this section forms a valuable supplement to a standard text-book, such as Hann's *Lehrbuch*, but is insufficient by itself to teach a student the groundwork of meteorology.

The section by E. Obst on the geographical distribution of climate includes only thirty pages, and is practically limited to a description of the various classifications of climate which have been proposed from time to time, and a series of statistical studies of the areas occupied by each of Köppen's types of climate in the different continents and oceans. The only illustrations are somewhat obscure diagrams representing these statistics graphically.

C. E. P. B.

British (Terra Nova) Antarctic Expedition 1910–1913. Observations on the Aurora. By C. S. WRIGHT. (Published for the Committee of the Captain Scott Antarctic Fund.) London (Harrison & Sons, Ltd.), 1921. 4° Pp. viii + 48. 7s. 6d. net.

One of the most fortunate circumstances in regard to the auroral work done by Captain Scott's last Antarctic expedition was the adoption of two observing stations, simultaneously occupied, about 450 miles apart. Such a separation, though of relatively small significance for some geophysical data, is of great importance for aurorae in high latitudes. The different characteristics of the aurorae as observed from the two stations constitute the most striking feature of Captain C. S. Wright's recently issued report on the auroral work, and render it an extremely valuable contribution to knowledge.

If the aurorae in the south are at heights similar to those determined in the northern hemisphere (as it is reasonable to suppose), aurorae visible overhead at either station must be very low down near the horizon of the other. Hence, unless the majority of the aurorae observed had lain between the two stations, which was not the case, the aurorae seen from the two stations must, in the main, have been different. Thus they represented conditions characteristic of the locality of each station. Both are close to the south magnetic pole, at comparable distances on opposite sides; but it seems probable that the factor which chiefly determines the difference between the aurorae in the two localities is their distance from the pole of the earth's magnetic axis, which, in the north, is roughly the centre of the belt of maximum frequency of auroral occurrence. This belt is generally supposed to be of about 23° radius, though it is not quite circular. Of the two Scott aurora stations, one, Cape Evans, is about 20° distant from the southern pole of the axis, while the other, Cape Adare, is at about 27° distance. The latter is not, however, as might be expected, outside the southern belt of maximum frequency (if such a belt exists), since the majority of aurorae visible from it are seen to the north. They are, moreover, about twice as frequent as those seen, under similar conditions, from Cape Evans, as well as being far more brilliant, mobile, and coloured. At Cape Evans aurorae appear more frequently in the direction slightly north of east. At both stations the trend of the aurorae is roughly perpendicular to the direction of maximum frequency of occurrence; also they usually first appear low down near the horizon, and gradually approach, moving overhead in the direction of minimum frequency. The overhead passage is rarer at Cape Evans than at Cape Adare.

In addition to pointing out these important differences, Captain Wright continues the discussion of the relation between aurorae and magnetic disturbance, already dealt with by Dr. Chree in the magnetic report of the expedition. There seems to be very little local connection between ordinary aurorae and the particular magnetic fluctuations occurring at the same time, but there is a strong correlation between brilliant aurorae and the general magnetic activity over a period of a few hours about the same epoch. S. C.

Frequented Ways. A general survey of the land forms, climate and vegetation of Western Europe, considered in their relation to the life of man; including a detailed study of some typical regions. By MARION I. NEWBIGIN. London, Bombay, Sydney (Constable & Co.), 1922. 8°. Pp. xi + 321, pls. 31. 15s. net.

In "Frequented Ways" Dr. Newbigin writes very pleasantly on many parts of Western Europe, and the geographical factors which have largely determined the distribution and the development of man in the regions which are described. While presenting a strictly accurate account of the geographical conditions prevailing, the descriptions are so attractive that they are sure to induce many of those who read them to visit the places that the authoress knows so well.

Meteorology enters of necessity to a greater or less extent into most of the geographical essays; and in a chapter on rain and sunshine the climatological conditions of Western Europe are well described, and the factors which determine their distribution are carefully explained.

The plan of the work is to discuss first the general characters of the land, taking hill and mountain, main routes of travel, different types of landscapes, etc., and to illustrate their special characters from actual districts. Some regions having special characteristics, such as the high alpine regions, the rock scenery of the Dolomites, the volcanic areas of Etna and Vesuvius; and town development as shown by towns in Provence and Transapennine Italy are discussed with special reference to the geographical types that they illustrate.

As a pleasant and very readable account of the regions it describes this book is to be highly recommended, but it has an even greater value as a book for school use from which may be learned the real spirit of geography in the study of the interaction of the many factors which make up the conditions of life in any part of the world. H. G. L.

Mean monthly air transport over the North Pacific Ocean. By W. WERENSKIOLD. *Kristiania, Geofysiske Publikationer,* Vol. 2, 1922, No. 9. Pp. 55.

Pilot charts of the oceans are prepared by the Hydrographic Office of the U.S. Navy Department, and these charts include, amongst other items, wind roses for 5-degree squares. In the memoir under review Werenskiold renders it possible to visualize, by means of stream lines and curves of equal velocity, the actual average monthly air transport. About half of the memoir is devoted to a useful description of the methods followed in the preparation of the diagrams and to a discussion of some patterns of stream lines represented by simple differential equations.

With regard to the method the following was the sequence of operations:—

(1) For each 5-degree square the resultant mean velocity was found (graphically) by vectorial addition.

(2) The N.-S. and E.-W. components were then treated separately; curves of equal values were drawn for each on separate sheets of tracing paper, and to avoid confusion these were done in red and green respectively. The curves of zero-components were drawn with double contours.

(3) The next step was to construct curves of equal direction—"isogones." The two sheets were fixed in place on a table, and the isogones were drawn on a third sheet placed uppermost. If k denote the tangent of the angle between the meridian and the direction of the mean velocity, then it will be seen that it is easy to draw the isogones—

$$\begin{array}{ll} k = 0, & k = \infty, \\ k = +1, & k = -1, \\ k = +\frac{1}{2}, & k = -\frac{1}{2}, \\ k = +2, & k = -2. \end{array}$$

Thus 8 isogones are obtained, corresponding to 16 wind directions. Further, if A and B denote the component curves, the intersecting points of the curves $A = O$ and $B = O$ (*i.e.* the curves of the zero components) are singular points, through which all isogones must pass, for the equation

$$B - Ak = O$$

is satisfied for all values of k at points where both $A = O$ and $B = O$.

(4) A great many short streaks are then ruled across each isogone, parallel to the direction of the vector represented by the isogone. Then the continuous stream lines are drawn free hand.

The last process is equivalent to a graphical integration of the differential equation $\frac{dy}{dx} = \frac{B}{A}$, and the author follows on with a mathematical discussion of some patterns of stream lines represented by simple differential equations of this form.

Coming now to the actual air transport over the North Pacific Ocean, the stream lines vary considerably from month to month, but some general traits are common to all seasons. The more striking features are as follow.

A strongly marked line of convergence runs westward from some point near the Isthmus of Panama (about Lat. 10° N.); to the south of this line are the South-East Trades, and to the north are the North-East Trades. These latter have their origin in the subtropic anticyclone centred about Lat. 30° N., Long. 140°-150° W.; from this centre usually there run two distinct lines of divergence, one south-eastward roughly parallel to the coast of California and Mexico and the other westward. The first line of divergence meets the above-mentioned line of convergence in a neutral point off Panama. The second line of divergence marks the northern limit of the North-East Trades. These wind systems remain fairly steady from month to month, and the charts may be taken to represent actual wind conditions.

Farther north conditions are very changeable, but even here there are also some features common to most months. Somewhere near the Aleutian Islands or in the great Bight of Alaska a cyclonic centre generally exists; to the west and north of this point is an area of Northerly winds, coming down the Bering Sea. Another feature common to most months is a line of convergence along the coast of British Columbia and Southern Alaska, and the author remarks that a similar line of convergence would certainly be found to exist along the west coast of Norway. In the western half of the North Pacific there is a distinct change between the winter and summer conditions.

There follows a short discussion of the relation of the stream lines to the pressure distribution, and finally a note on wind and precipitation.

The memoir is an interesting attempt to view the question of atmospheric circulation in its mathematical aspects, and any one intending to deal with similar collections of statistics would be well advised to make a careful study of the memoir and in particular of the methods expounded.

A. H. R. G.

Collected scientific papers of John Aitken, LL.D., F.R.S. Edited for the Royal Society of Edinburgh (with introductory memoir) by Cargill G. Knott. Cambridge University Press, 1923. 8°. Pp. xxi + 591. 30s. net.

Shortly after the death of Dr. John Aitken the Royal Society of Edinburgh entrusted the preparing of a volume containing his most important papers to Dr. Cargill G. Knott, LL.D., D.Sc., F.R.S., a legacy of £1000 having been left by Dr. Aitken for this purpose.

The volume of collected papers contains an account of the work of Aitken upon dust, fogs, clouds and dew, for which his name has become so well known, as well as other less-known papers, and is prefaced by a short sketch of his life by Dr. Knott.

It is necessary that any one reading this volume should realize that it is not a connected account of a single research but a number of papers written at long intervals and ultimately collected together. The work described is largely experimental and is of the greatest interest and value to all who are concerned with meteorology, and more particularly with problems connected with the pollution of the air by dust. The pioneer work done by Aitken and made possible by his remarkable gifts for experimental research, throws light upon many problems previously neglected. It is probable, however, that Aitken would have been the last to believe that his researches had reached finality and gave a complete explanation of the phenomena referred to. This is more particularly true in the case of his great work in connection with the measurement of dust particles in the air. This volume contains detailed descriptions of his instruments for dust counting and of experiments and tests made therewith. It is, however, to be regretted that a certain amount of doubt surrounds the results, and it is fairly evident that the feeling was present to Aitken's mind as it must be to an impartial reader of these collected papers. It appears evident that Aitken set himself primarily the problem of measuring the degree of pollution of the air by dust, using the word in its ordinary meaning. This is clear from the general trend of his papers, which refer over and over again to dust, without any qualification ; for example, summarizing his experiments on dust, fogs and cloud he says :—

(1) That when water vapour condenses in the atmosphere it always does so on some solid nucleus.
(2) That the dust particles in the air form the nuclei on which it condenses.
(3) If there was no dust in the air there would be no fogs, no clouds, no mists, and probably no rain.

Again he says, speaking of the origin of dust :—"Everything in nature which tends to break up matter into minute parts will contribute its share . . . there is also meteoric dust, volcanic dust, and condensed gases." He then goes on to develop the method of depositing dust for estimation by causing water to condense upon it, but on page 49 we find the following definition : "When speaking of the dust produced by combustion I do not mean the dust usually spoken of in connection with fires as it is comparatively heavy and soon settles to the ground, nor do I refer to smoke or soot ; the dust I refer to is the invisible dust, so fine that it scarcely settles out of the air." We find on p. 284 another definition in which he says: "It would be better to keep to the use of the same terms, and as usual, under the name of 'dust particles,' to include all solid and liquid products of combustion of whatever size or colour they may be." It would almost seem as if the meaning which Aitken himself attached to the word "dust" varied from time to time. It is now known that the particles estimated in Aitken's dust counter are simply nuclei of condensation, whether liquid or solid, and this fact, together perhaps with some ambiguity in his own papers, has given rise to many mistakes in interpreting

Aitken's work. It appears from some of Aitken's remarks that he believed that all dust particles acted as nuclei; for example, on p. 188, referring to the dust particles in the air being made visible by condensation, he says: "A stage was arrived at in which every particle was made visible."

Many of the experiments and conclusions given in his earlier papers have to be taken as doubtful in the light of his own subsequent experiments; for example, the statement on p. 197 that air drawn through 12 inches of tightly packed cotton wool carried dust with it; as he subsequently found, the production of nuclei occurred very easily, such as by splashing of water, and he traced the nuclei, which apparently passed the cotton wool, to the manner of wetting the inside of his flask.

He describes many very beautiful experiments, devised and carried out by him, including trials made with his Koniscope in which an attempt is made to measure the number of dust particles by the colours obtained in a condensed cloud viewed by transmitted light (p. 280), and the spirit of his research may be perhaps best understood by his own remarks in connection with this experiment, when later on he says: "It is to be regretted that this investigation does not promise to yield much of practical value, nevertheless, as we cultivate not only fruit but flowers, so for the same reason that we cultivate the latter, it is thought that these experiments will repay the attention of physicists" (p. 283).

While Aitken's conclusions may sometimes have to be modified in the light of further research, this need not detract from the value of the work described in these papers, which should be read by all who are interested in the impurities in the air and their effect in causing fogs, cloud and haze. J. S. O.

Recherches sur les grands vents près de la côte suédoise du Golfe de Botnie. Par C. J. Östman. *Stockholm, Statens Meteorologisk-Hydrografiska Anstalt, Meddelandan,* 1922, Bd. 1, No. 4. Pp. 45, pls. 2.

In the Swedish Meteorological Service special provision is made for detailed observations during periods when the wind force reaches or exceeds Beaufort force 7. At the stations of the Meteorological and Hydrographical Institute, observers are instructed to make hourly observations during such periods and to note in particular (*a*) the highest force reached, with the time, and (*b*) the times of onset of forces 7 and 10, and of forces 8, 9, 11 and 12 if possible.

Observations on somewhat similar lines are also available from a number of lighthouses. These records, supplemented by a number of less detailed observations, have been utilised by C. J. Östman in preparing this very comprehensive paper on the high winds on the Swedish side of the Gulf of Bothnia.

After some introductory details as to the position and equipment of the stations and the methods of observation, the author proceeds to a statistical analysis of the data for eleven stations at which hourly observations are available. The first series of tables gives for each station the total number of hours in each calendar month of the period 1907 to 1921 during which the wind was force 7 or above from each of sixteen points of the compass, together with means for direction and yearly means independent of direction. Corresponding tables, with force 10 as the lower limit, follow.

An examination of the tables reveals the fact that at most of the stations high winds occur most frequently when the direction is parallel to the coast, that is to say, when the direction is near NE or SW. The northerly maximum frequency is more prominent in spring and summer, and the southerly in autumn and winter.

Combining the results for all stations and for the whole year it appears that the wind reaches force 7 or above during 4·4 per cent of all hours and force 10 or above during 0·5 per cent of all hours. The average number of days (midnight to midnight) per year on which high winds are experienced is 37·8, the maximum occurring in November at most stations. This section of the paper contains numerous other statistical results, among which may be mentioned a correlation coefficient of + 0·62 between the annual number of hours of wind of force 10 or above, between S and SW, and Wolfer's sunspot numbers.

The remaining sections of the paper are devoted to the relation between the wind and the pressure gradient, the deviation of wind direction from the gradient direction and the "synoptic situation" associated with high winds. These matters are considered in great detail, and the author has obtained a number of interesting results. One of these is that the gradient increases more rapidly than the wind in a region where pressure is falling, and the reverse is believed to hold in a region where pressure is rising. Consequently the ratio of the observed wind speed to that corresponding to the gradient is dependent upon the sign and magnitude of the rate of change of pressure. It would be interesting to test this conclusion using British data; one's general impression is that it would be confirmed.

The paper is to be welcomed as an important addition to our knowledge of the winds in the Northern Hemisphere. E. G. B.

On Exposures of Thermometers in India. By J. H. FIELD. *Memoirs of the Indian Meteorological Department*, Vol. **24**, Part 3, Calcutta, 1922. 2s.

The standard method adopted for the exposure of thermometers at the Indian Observatories has hitherto been to place the instruments in a cage which is hung under the shelter of a shed measuring 20 feet by 16 feet, with open sides and a thick roof of thatch. Stevenson screens are used only at stations of the third and fourth class, and it appears to have been assumed that they did not afford sufficient protection against a tropical sun, especially in calm weather.

In a discussion on the "Best Form of Thermometer Stand" at a meeting of this Society in November 1873 the late Dr. R. H. Scott said,[1] "It is perfectly certain that a stand which will suit a climate like England will not suit an Indian climate. . . . We in the Meteorological Office are now asked to devise a form of stand for China. If I should say, send a 'Stevenson' stand, we should find that that would not suit without alteration."

This view does not seem to have been seriously questioned since, but the large thatched shed is not a convenient form of shelter in some circumstances, and involves some risks from fire in a hot and dry climate. The object of the experiments described in this *Memoir* was to ascertain what differences, if any, would be introduced by the adoption of some more convenient method of exposure. The experiments, which took place at Agra and lasted for a full year, were carried out with great care and much detail. In addition to the thatched shed, two other sheds were tried with tiled roofs, and there were Stevenson screens both in the open and with different forms of auxiliary protection from the sun's rays. There was also an Assman psychrometer and an open-air motor-ventilated and jacketed draught-tube which was treated as the standard of reference.

The result of the experiments was that the Stevenson screen, very slightly modified from the pattern used in this country and without any auxiliary protection, came through the ordeal surprisingly well, and of all the exposures employed it compared much the best with the ideal, but expensive, arrangement of ventilated instruments. The comparison with the thatched shed, with which the normal values for Indian stations have been determined, shows that no material errors would be introduced by replacing the sheds by Stevenson screens.

The result will be of much interest to Fellows of this Society, as the Society took a leading part in securing the adoption of the Stevenson screen as the standard in this country, and the specification of the screen which is in general use was the work of a Committee of this Society in 1883.[2] H. M.

[1] *Q. J. R. Meteor. Soc.* **2**, 1874, p. 40. [2] *Q. J. R. Meteor. Soc.* **10**, 1884, pp. 92-94.

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Printed in Great Britain by R. & R. Clark, Limited, *Edinburgh.*

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